Leidy, Robert

From: Leidy, Robert
Sent: Tuesday, July 22, 2014 11:12 AM
To: Lomeli, Ben
Cc: Jeffrey Simms; Simms, Karen M
Subject: RE: SWCA Revised FEIS modeling approach

Thanks Ben,

I have this report. I was referring to a “new” SCWA analysis that Chris Garrett just told me he is trying to finalize for tomorrow. It’s difficult to keep track of all the new reports.

Thanks again,

Best,

Rob

____

Robert A. Leidy, Ph.D.
U.S. Environmental Protection Agency
Wetlands Office (WTR-8)
75 Hawthorne Street
San Francisco, CA 94105
(415) 972-3463

From: Lomeli, Ben [mailto:blomeli@blm.gov]
Sent: Tuesday, July 22, 2014 11:08 AM
To: Leidy, Robert
Cc: Jeffrey Simms; Simms, Karen M
Subject: Re: SWCA Revised FEIS modeling approach

Robert,

Sorry for delayed response. I have been off on sick leave (still am) but hope to make it in for tomorrow's meeting. I believe the attached PDF is what you are referring to (looking for).
If not, please call my cell ((b) (6) [redacted]), as I may not otherwise recheck my email today.

On Mon, Jul 21, 2014 at 11:05 AM, Leidy, Robert <Leidy.Robert@epa.gov> wrote:

> Ben,

Do you have a copy of the latest SWCA referred to in their Revised FEIS modeling approach? If so, you please forward it to me. Can't seem to get a response from the Forest Service.

Thanks,

Rob

____

Robert A. Leidy, Ph.D.

U.S. Environmental Protection Agency

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75 Hawthorne Street

San Francisco, CA 94105

(415) 972-3463

From: Lomeli, Ben [mailto:blomeli@blm.gov]
Sent: Thursday, June 26, 2014 10:48 AM
To: Julia Fonseca; Mark D'Aversa; Simms, Jeffrey R; Leidy, Robert; Shafiqullah, Salek -FS; Simms, Karen M; Viola Hillman; Daniel Moore; Paul Summers; Jean_Calhoun; Jason Douglas; Marcia Radke; David Murray; Jeanmarie Haney; Jesse Dickinson; Stanley A Leake
Subject: Sonoita Area Existing Pumpage

Hi all,

Attached please find a PDF of a 2005 groundwater study quantifying pumpage in the Sonoita area.

This is critical information that should be but has not been included in the Rosemont Mine models. Existing pumpage is likely already having, or will have, some effects on the LCNCA surface water resources, including springs, wetlands and Cienega Creek and its tributaries.

An update of this information would be most appropriate; and it is available. It should help reduce/clarify one of the many "uncertainties" of the models.

When we only have a little bit of water, every little bit matters if we want to truly evaluate additional impacts as required by NEPA. (Good hard look & cumulative impacts).

--

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(520)258-7207

"*We do not inherit the Earth from our ancestors, we borrow it from our children.*" Native American Proverb.

--
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"*We do not inherit the Earth from our ancestors, we borrow it from our children.*" Native American Proverb.

REVIEW OF USFS MODEL AND AN ALTERNATIVE APPROACH TO INFORM THE EFFECTS OF GROUNDWATER DRAWDOWN ON CIENEGA CREEK

Prepared for: Coronado National Forest

Prepared by: Rosemont Copper Company

Date: June 6, 2014

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EXECUTIVE SUMMARY

The USFS developed a model (referred to hereafter as the October 2013 Model) to attempt to quantify the impact to surface water resources in Upper Cienega Creek and its tributaries resulting from the modeled groundwater drawdown from the Rosemont Copper Project (the Project). In this document, we provide a critique of the October 2013 Model and discuss its appropriateness for use in an ESA Section 7 consultation. In addition, we provide an alternative approach toward the assessment of potential impacts to these surface water resources.

There are six major assumptions or issues associated with the October 2013 Model which make it inappropriate for use in identifying surface water impacts that are reasonably certain to occur as a result of the Project. Specifically, the model:

1) Does not fully incorporate into its analysis the physical processes that govern the interaction between surface water and groundwater,
2) Assumes that when the water level is at, or below, the bottom of the v-notch weir at USGS Gage #09484550 on Upper Cienega Creek (i.e. there is no recorded flow), the drainage is dry,
3) Assumes that surface water dynamics at the USGS gage are exactly the same as the surface water dynamics along all of Upper Cienega Creek, Empire Gulch, and Gardner Canyon,
4) Overestimates the impact of drawdown on Upper Cienega Creek by inappropriately assuming that reductions in stream flow in the tributaries of Upper Cienega Creek result in additional drawdown in Upper Cienega Creek that is not accounted for in regional groundwater models,
5) Assumes that groundwater drawdown results in an equivalent reduction in the depth of surface water, and
6) Uses sensitivity analyses performed by Tetra Tech (2010) and Montgomery & Associates (2010) to bound the analysis of groundwater effects.

In our analysis of the October 2013 Model, we illustrate that its results are highly sensitive to these issues/assumptions. In some cases, model results are simply a consequence of these assumptions. As such, the conclusions of the October 2013 analysis are highly speculative and therefore not appropriate use in the Endangered Species Act Section 7 consultation process.

In this document we describe an alternative approach to evaluate the potential effects of groundwater drawdown on Upper Cienega Creek and its tributaries. This approach is based on a combination of empirical data collected on wetted stream length along Upper Cienega Creek and its tributaries, and predictions from two of the regional groundwater models. Briefly, using data on wetted stream length, we fit several distributions to these data. We used the two best fit distributions to calculate the probability that over the next 176 years (150 years post mining) and 1,026 years (1,000 years post-mining) Upper Cienega Creek and its tributaries would be dry. By using empirical data to calculate the risk of these resources going dry, we avoid many of the problematic assumptions used by the October 2013 Model, and rely on far fewer assumptions.

The results of our analyses indicate that the risk that Upper Cienega Creek and its tributaries will be completely dry, or dry to less than 1 mile, as a result of drawdown from the mine is small, and under most

scenarios highly improbable. For instance, the probability that Upper Cienega Creek and its tributaries will go dry in 1,026 years as a result of the Rosemont Copper Project is between 0.01 and 0.05%. Assuming even the most severe predictions of recent climate change models, this probability increases to a range of only 0.03 to 0.37%.

1. INTRODUCTION

This document has been developed to address questions and confusion regarding potential effects of the Rosemont Copper Project (the Project) on the aquatic resources in Cienega Creek and two key tributaries, Empire Gulch and Gardner Canyon, as a result of potential groundwater drawdown. A very abbreviated history of the analysis of these potential effects, as Rosemont Copper Company (Rosemont) understands it, is as follows:

- In July 2013, the U.S. Forest Service (USFS) published a Preliminary Administrative Final Environmental Impact Statement (PAFEIS) for the Project that provided, in general, a narrative, qualitative assessment of the potential impacts to the subject aquatic resources. The analysis of effects was based, in part, on a substantial and rigorous review of three groundwater models developed for the Project (Tetra Tech [2010], Montgomery & Associates [2010], and Myers [2010]). The analysis included in the PAFEIS acknowledged the limitations of the groundwater models to predict impacts to resources that were distant in time (1,000+ years) and space (>10 miles).

- In October 2013, the U.S. Fish and Wildlife Service (FWS) finalized the Biological Opinion (BO) for the Project based, in part, on the analysis provided in the PAFEIS. The analysis in the BO, however, was more quantitative in nature and assumed a greater degree of accuracy and precision on the part of the groundwater models than was assumed in the PAFEIS.

- Also in October 2013, in response to comments from the U.S. Environmental Protection Agency (EPA), the USFS prepared a memorandum (SWCA 2013) that utilized a coarse model to attempt to translate the groundwater drawdown predicted by the Tetra Tech groundwater model (ostensibly the most conservative for the purpose of this analysis) into a potential loss of surface water resources. Given the assumptions used in this model (referred to hereafter as the "October 2013 Model"), described further below, the results of this analysis described a very broad range of potential effects to the subject surface water resources.

- In December 2013, the USFS published the Final Environmental Impact Statement (FEIS) with a revised discussion of impacts to the subject aquatic resources based on the October 2013 Model described in SWCA (2013).

This document has been developed by Rosemont to provide a critique of the October 2013 Model to inform the potential effects due to groundwater drawdown of the Project on Cienega Creek and its tributaries, and an alternative approach towards the assessment of potential impacts. First, we provide a review of the October 2013 Model, a discussion of the major assumptions of the analysis, and an assessment of how much influence these assumptions have on the results of the model. We then describe an alternative approach to inform the risk that Upper Cienega Creek will go dry, and use this approach to analyze the effects of groundwater drawdown on Upper Cienega Creek.

2. REVIEW OF THE OCTOBER 2013 MODEL

The purpose of the analysis performed by SWCA (2013) was to disclose the range of possible impacts to surface water in Lower Cienega Creek, Upper Cienega Creek, Empire Gulch, and Gardner Canyon in support of the National Environmental Policy Act (NEPA) process for the proposed Rosemont Copper Project. The analysis uses data from a USGS steam gage 09484550 on Upper Cienega Creek and predicted groundwater drawdown from regional groundwater models to predict the average number of days in a year that these drainages would be dry. The October 2013 Model, however, does not distinguish between reasonably likely impacts and highly speculative impacts and relies on several key assumptions that are neither supported by available data nor tested to inform their influence on model results. Review of the specifics of the SWCA (2013) analysis and the available data indicate that the results of the analysis are largely a consequence of the assumptions made to develop the October 2013 Model. Consequently, the results of the October 2013 Model are speculative, and have limited utility to inform permitting processes such as the Endangered Species Act Section 7 consultation process for the Rosemont Copper Project.

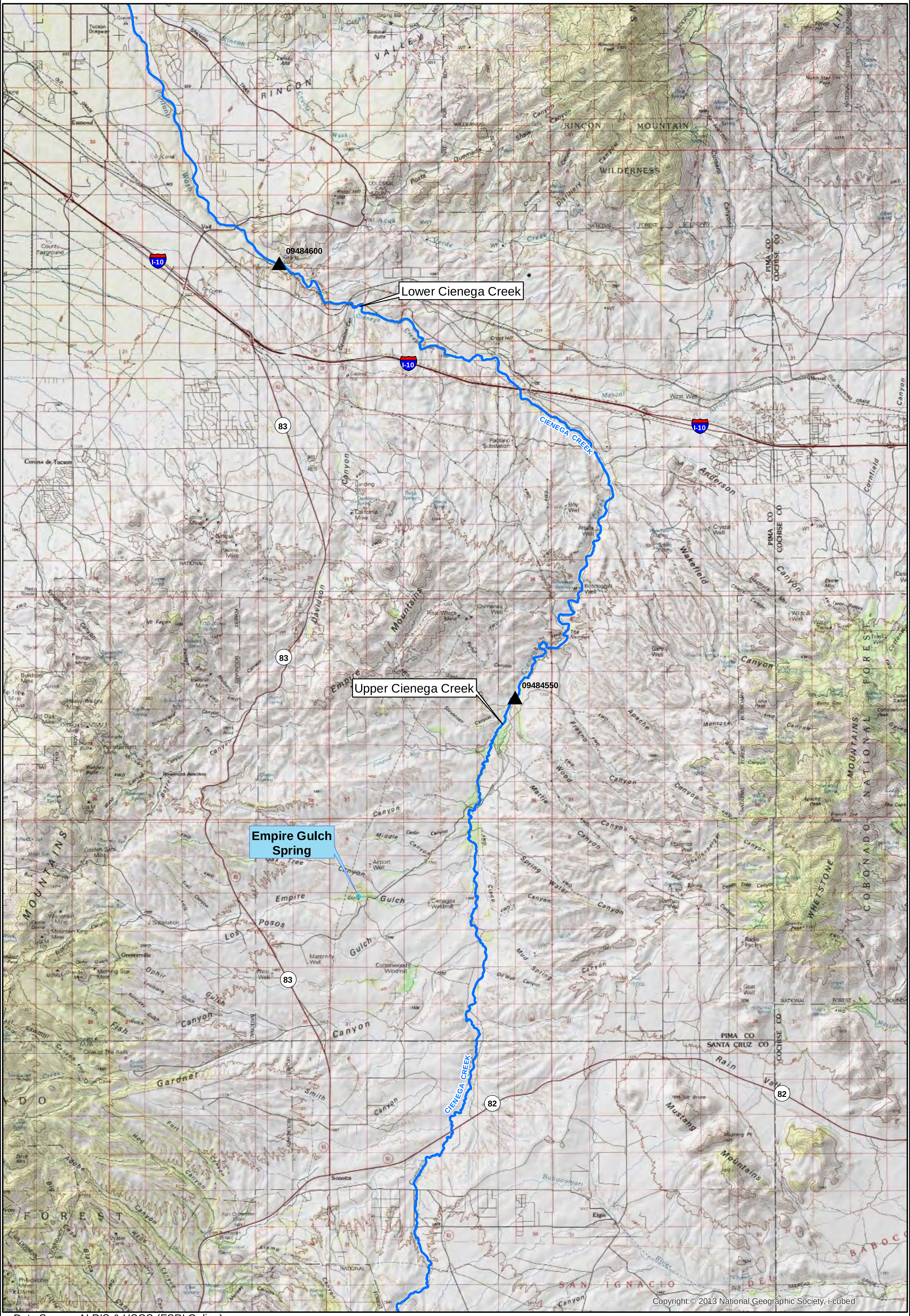
Below we describe the data used and specific steps associated with the analysis presented by SWCA (2013), outline the major assumptions on which the October 2013 Model is based, review the available data and theory that inform the reasonableness of these assumptions, and quantify how sensitive the results of the October 2013 Model are to these assumptions.

2.1. OCTOBER 2013 MODEL

The October 2013 Model is based on historical measurements at the USGS stream gage 09484550 on Upper Cienega Creek taken between August 18, 2001 and October 28, 2013. The stream gage is associated with a v-notch weir to measure flows in Cienega Creek approximately 17.4 miles upstream of the confluence with Davidson Canyon (***Figure 1***).

From the available gage data, SWCA (2013) calculated a daily measure of depth of water at the gage but assumed that no flow at the gage equated to a water depth of zero feet at the gage. SWCA (2013) defined a water depth at the gage of zero feet as a “dry day”, and then calculated an average number of “dry days” per year over the 12-year period of available gage data. This number was considered the base case, or pre-mining condition, of the number of “dry days” in Upper Cienega Creek, Empire Gulch, and Gardner Canyon.

To analyze the effect of groundwater drawdown as a result of mining activities on the presence of water in Upper Cienega Creek, Empire Gulch, and Gardner Canyon, SWCA (2013) assumed that drawdown in the regional aquifer equates to an equal reduction in the depth of water at the USGS stream gage. SWCA (2013) then calculated the number of “dry days” per year that would result at each drainage after taking into account drawdown predicted by regional groundwater models. The predicted drawdown was subtracted from the average daily gage height, and if this resulted in a stage below the v-notch weir, it was considered a “dry day”. The October 2013 Model also assumed that if Empire Gulch and Gardner Canyon are predicted to have a drawdown that exceeds the threshold of 0.3 feet, additional drawdown in Upper Cienega Creek would be realized.



Data Source: ALRIS & USGS (ESRI Online)

N

0 5,000 10,000 Feet

0 2 Miles

Legend

▲ USGS Gaging Station

Spring

WestLand Resources, Inc.
Engineering and Environmental Consultants

Review of USFS Model and An Alternative Approach to Inform the Effects of Groundwater Drawdown on Cienega Creek

Overview Map
Figure 1

The result of this analysis is a series ot tables that illustrate the predicted average number of "dry days" per year along Upper Cienega Creek, Empire Gulch, and Gardner Canyon under five scenarios: the best fit models for each of the three regional groundwater model (Tetra Tech [2010], Montgomery & Associates [2010], and Meyers [2010]), a minimum drawdown case, and a maximum drawdown case. These latter two scenarios were based on the sensitivity runs of Tetra Tech (2010) and Montgomery & Associates (2010) and predictions from Meyers (2010). The results were presented at different periods following the cessation of mining: 50 years, 150 years, 1,000 years (***Table 1***). Identical methods were used to calculate the number of "low flow" days in Upper Cienega Creek, defined as the number of days where the calculated depth of water at the USGS gage was less than 0.2 feet (SWCA 2013)(***Table 2***).

Table 1. Number of "dry days" per year predicted by October 2013 Model.

Period	Drainage	Number of Dry Days per Year				
		Minimum Drawdown Case	Best Fit[1]			Maximum Drawdown Case
			Model 1	Model 2	Model 3	
50 years post mine closure	Upper Cienega Creek	3	3	3	3	4
	Empire Gulch[2]	3	3	4	283	361
	Gardner Canyon	3	3	3	3	3
150 years post mine closure	Upper Cienega Creek	3	3	3	32	313
	Empire Gulch[2]	3	32	32	363	365
	Gardner Canyon	3	3	3	4	146
1,000 years post mine closure	Upper Cienega Creek	3	3	125	351	351
	Empire Gulch[2]	363	364	365	365	365
	Gardner Canyon	3	3	283	363	363

[1] *SWCA (2013) does not match regional groundwater models to predictions of "dry days" in the October 2013 Model.*
[2] *Note that given the approach taken by SWCA (2013) to calculate "dry days", these rows reflect Empire Gulch Springs, and not lower Empire Gulch which is predicted to experience considerably less groundwater drawdown.*

Table 2. Number of "extreme low-flow days" per year predicted by October 2013 Model.

Period	Drainage	Number of Extreme Low-Flow Days per Year				
		Minimum Drawdown Case	Best Fit[1]			Maximum Drawdown Case
			Model 1	Model 2	Model 3	
50 years post mine closure	Upper Cienega Creek	4	4	4	4	146
	Empire Gulch2	4	4	146	352	362
	Gardner Canyon	4	4	4	4	88
150 years post mine closure	Upper Cienega Creek	4	88	88	283	352
	Empire Gulch[2]	4	283	283	364	365
	Gardner Canyon	4	4	32	146	349
1,000 years post mine closure	Upper Cienega Creek	88	88	339	354	354
	Empire Gulch[2]	363	364	365	365	365
	Gardner Canyon	4	4	352	363	363

[1] *SWCA (2013) does not match regional groundwater models to predictions of "dry days" in the October 2013 Model.*
[2] *Note that given the approach taken by SWCA (2013) to calculate "dry days", these rows reflect Empire Gulch Springs, and not lower Empire Gulch which is predicted to experience considerably less groundwater drawdown.*

The utility of the approach taken by SWCA (2013) to analyze groundwater impacts on Upper Cienega Creek and its tributaries is limited because of six major issues. Specifically, the October 2013 Model:

1) does not fully incorporate properly into its analysis the physical processes that govern the interaction between surface water and groundwater,
2) assumes that when the water level is at, or below, the bottom of the v-notch weir at USGS gage 09484550 on Upper Cienega Creek, the drainage is dry,
3) assumes that surface water dynamics at the USGS gage are exactly the same as the surface water dynamics along all of Upper Cienega Creek, Empire Gulch, and Gardner Canyon,
4) inflates the impact of drawdown on Upper Cienega Creek by inappropriately assuming that reductions in streamflow in the tributaries of Upper Cienega Creek results in additional drawdown in Upper Cienega Creek that is not accounted for in regional groundwater models,
5) assumes that one foot of groundwater drawdown results in a one foot reduction in the depth of surface water, and
6) uses sensitivity analyses performed by Tetra Tech (2010) and Montgomery & Associates (2010) to bound the analysis of groundwater effects.

In the sections that follow, we discuss the issues described above, and analyze, when possible, how each affects the results of the October 2013 Model.

2.2. The October 2013 Model Does Not Fully Incorporate into its Analysis the Physical Processes that Govern the Interaction between Groundwater and Surface Water

The October 2013 Model did not account for the controlling physical processes that drive the interaction of groundwater and surface flows. The change in stream flows attributable to groundwater levels is a function of the groundwater discharge to the stream, not simply the change in groundwater level. Flow between streams and aquifers can be computed using Darcy’s Law and this relationship was used in the Rosemont groundwater flow models (Tetra Tech 2010, Montgomery & Associates 2010) to predict stream flow. Streams gain flow when groundwater levels are higher than the stream stage, and lose flow when the stream stage is higher than the groundwater levels. Using Prudic (1989), flow between a stream and aquifer over a given section is computed as.

$$Q_L = \frac{KwL}{m}\left(h_a - \Delta h_a - (h_s + y)\right) \tag{1}$$

Where
Q_L = volumetric flow into a stream from aquifer (volume per time)
K = hydraulic conductivity of streambed sediments (length per time)
w = representative stream width (length)
L = the length of the stream (length)
m = thickness of the streambed deposits (length)
h_s = elevation of the bottom of the stream (length)
h_a = elevation of the ground water aquifer (length)
Δh_a = aquifer drawdown (length)
y = depth of water above bottom of stream (length)

Equation 1 shows that the flow of water into or out of a stream is a function of the aquifer elevation, and that a change in the aquifer elevation will change the flow rate, but it does not relate the aquifer elevation to the depth of water in the stream. The depth of the water in the stream is a function of the flow rate, the channel slope, and the channel roughness. ***Equation 2*** is Manning's equation for a steady-state stream, with a rectangular cross-section that does not spatially vary. This equation can be used to derive stream length.

$$Q_s = \frac{1.49}{n} wy \left(\frac{wy}{w+2y}\right)^{2/3} \sqrt{S} \tag{2}$$

Where Q_s = volumetric flow in the stream (volume per time)
n = channel roughness (no units)
w = representative stream width (length)
S = the slope of the stream (length/length)
y = depth of water above bottom of stream (length)

Equation 3 is a combination of ***Equations 1*** and ***2***. ***Equation 3*** is a simplified version of the actual physics because ***Equation 2*** does not account for water entering or leaving the stream along its length, but it does show that the relationship between drawdown in the aquifer, Δh_a, and depth of water in the stream, *y*, is very complicated, and that the depth in the stream does not vary in a 1:1 ratio with the aquifer depth.

$$\Delta h_a = \frac{1.49my\left(\frac{wy}{w+2y}\right)^{2/3}\sqrt{S}}{nKL} - \left(h_a - (h_s + y)\right) \tag{3}$$

As noted above, ***Equation 3*** is a very simplified version of the interaction between the aquifer and a stream. In reality, the channel cross-section, the channel roughness, and the slope, and the flow in the channel can change continuously through the length of the channel.

The October 2013 Model acknowledges the importance of these conditions several times:

1) "…at any given location the channel geometry is constantly shifting over time in response to sediment loads and changes in flow unless there is good channel control, such as at the USGS streamgage. It is impossible to predict exactly how any given cross-section would change over the extremely long periods of time used in the analysis." (SWCA 2013, page 8)
2) "water levels clearly vary widely in Cienega Creek. This is not unexpected, as channel geometry and flow characteristics are highly variable, even in short distances." (SWCA 2013, page 7)
3) "Actual impacts to streamflow at any given location along Upper Cienega Creek would depend on the specific channel geometry, hydraulic connection with regional aquifer, and riparian vegetation characteristics at a specific location." (SWCA 2013, page 8)

Despite these acknowledgements, the October 2013 Model implicitly concludes that only groundwater and surface water levels are considered in their analysis of the effects of groundwater drawdown on

Upper Cienega Creek, Empire Gulch, and Gardner Canyon. This conclusion is in direct contradiction to the statements above from SCWA (2013).

The regional groundwater models, Tetra Tech (2010) and Montgomery & Associates (2010), incorporate and integrate the physical processes that control groundwater flow and stream flow in the Project area into a regional analysis. Project related impacts are due to changes in groundwater levels, or drawdown, due to mine dewatering and pit-lake formation. The models simulate the timing and magnitude of drawdown, which manifests as decreases in stream flow and riparian vegetation evapotranspiration. Regardless of cause, a decrease in groundwater level reduces evapotranspiration by riparian vegetation, which further attenuates any decrease in stream flow.

As shown in ***Equation 1***, groundwater flows from areas of high water-level elevations to areas with lower water-level elevations. Water levels in the surrounding mountains and upper basin are higher than the water levels near Upper Empire Gulch Spring and Upper Cienega Creek, which results in groundwater flow toward the creek. The volume of groundwater discharging to Upper Cienega Creek depends on many factors, but the conditions that change due to mining are being evaluated. Physical properties such as recharge, hydraulic conductivity, and storage are assumed to remain constant over the course of the analysis. Changes in groundwater levels, or drawdown, result in changes to the hydraulic gradients, groundwater flow rates, and ultimately stream flow rates.

Tetra Tech (2010) utilizes the SFR1 package (Prudic et al., 2004), which is based on ***Equation 1***. The predicted reduction in Cienega Creek base flow 1,000 years after mining ends was 0.09 cfs, which was 3-percent of the simulated base flow. This estimate was based on the physical processes that govern groundwater and surface water interactions and it is the best estimate of stream flow impacts to Cienega Creek.

Although the groundwater models are able to predict changes in stream flow based on changes to the hydraulic gradient between the aquifer and the stream, the depth of water in the stream is based on the flow rate, the channel slope, the channel shape, and channel roughness. These values change constantly along a drainage, and change from year to year. This is why, for a given stream flow, the depth of water in the channel could easily vary from 0.2 feet to 2 feet within 10 feet of stream length. ***Equation 1*** shows that streams can continue to flow when the groundwater level is below the streambed if the streambed sediments have sufficiently low permeability. Flowing reaches expand and recede depending on the volume of shallow water, evapotranspiration rates, and streambed permeability.

In summary, the approach used in the October 2013 Model to quantify stream impacts does not incorporate the physical processes that govern groundwater and surface-water interactions. It is not an acceptable approach for quantifying stream flow impacts. The regional groundwater model results provide quantitative estimates for impacts to Cienega Creek flows, resulting from the groundwater drawdown associated with mine operations and conditions after closure. The groundwater flow model impact estimates are considered conservative (i.e. over-estimate impacts) because the model assumes that Cienega Creek is hydraulically connected to the regional groundwater system along its entire reach, which is not the case. Predicted changes in flow may not materialize over these reaches as the local geology plays a significant role in driving shallow alluvial groundwater to discharge at the surface, and

Cienega Creek may be hydraulically disconnected from the regional groundwater system over significant reaches.

2.3. Sensitivity of the October 2013 Model to Assumptions

The October 2013 Model is based on a number of simplifying assumptions, which have been described above. The following sections address these assumptions, and examine the sensitivity of the model results to revisions to these assumptions that are informed by empirical data.

2.3.1. The October 2013 Model Assumes that the Depth of Water at Cienega Creek Gage is Equal to Zero When Flow is Equal to Zero

The USGS gage 090484550 on Upper Cienega Creek is in an area of bedrock and includes a v-notch weir for measuring low flows. The October 2013 Model assumes that if the water level at the USGS gage is at or below the bottom of the v-notch, the water depth at the gage is zero and Upper Cienega Creek, Empire Gulch, and Gardner Canyon are dry. Three lines of evidence contradict this assumption:

1) the available USGS rating curve for stream gage #098484550,
2) empirical data collected on the depth of water relative to the weir, and
3) wetted stream length data collected in Upper Cienega Creek and its tributaries.

USGS rating curve

The rating curve for the gage models a stage of approximately 0.6 feet when the water level is at the bottom of the v-notch (zero flow over the weir, ***Figure 2***). Therefore, under the assumption that stage height equates to depth of water, the water depth in Upper Cienega Creek is 0.6 feet when the water level is at the bottom of the weir (i.e., no flow).

Empirical data on water depth at the weir

On Wednesday, May 21, 2014, WestLand staff measured water depths upstream and downstream of the weir at USGS gage #09484550. ***Table 3*** shows the depth of water measured at various locations relative to the bottom of the v-notch weir. Two pools immediately downstream of the weir were also measured, and were approximately 2-6 feet deep.

Table 3. Water depths upstream and downstream of weir at USGS gage 09484550.

Water Depth Relative to the bottom of the Weir (feet)	Location
1.67	Portion of pool immediately adjacent to USGS gage.
0.94	Portion of pool immediately upstream of weir.
0.48	Northwest portion of pool opposite USGS gage.
0.67	At staff on northwest side of pool (approximately 6 feet upstream of weir).
1.21	Middle of channel next to staff.

EXPANDED RATING TABLE

Stage (ft)	Discharge (ft3/s) .00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER .1 UNITS
0.60					0.0000*	0.0003	0.0005	0.0008	0.0010*	0.0020	0.006
0.70	0.0034	0.0054	0.0080*	0.0107	0.0140	0.0177	0.0220*	0.0271	0.0329	0.0394	0.043
0.80	0.0466	0.0546	0.0633	0.0729	0.0834	0.0947	0.1069	0.1200*	0.1340	0.1489	0.118
0.90	0.1649	0.1818	0.1998	0.2188	0.2388	0.2600	0.2823	0.3057	0.3303	0.3561	0.218
1.00	0.3830	0.4112	0.4406	0.4713	0.5032	0.5365	0.5710	0.6069	0.6441	0.6828	0.340
1.10	0.7228	0.7642	0.8070	0.8513	0.8970	0.9442	0.9930	1.043	1.095	1.148	0.480
1.20	1.203	1.260	1.318	1.377	1.439	1.501	1.566	1.632	1.700	1.770*	0.634
1.30	1.837	1.905	1.974	2.045	2.118	2.192	2.267	2.344	2.422	2.502	0.747
1.40	2.584	2.667	2.752	2.838	2.925	3.015	3.106	3.198	3.292	3.388	0.901
1.50	3.485	3.584	3.684	3.787	3.890	3.996	4.103	4.212	4.322	4.434	1.063
1.60	4.548	4.663	4.781	4.900	5.020	5.143	5.267	5.392	5.520	5.649	1.232
1.70	5.780	5.913	6.048	6.184	6.322	6.462	6.604	6.748	6.893	7.041	1.410
1.80	7.190	7.340	7.493	7.648	7.804	7.963	8.123	8.285	8.449	8.615	1.592
1.90	8.782	8.952	9.124	9.297	9.472	9.650	9.829	10.01*	10.21	10.42	1.848
2.00	10.63	10.84	11.06	11.28	11.50	11.72	11.94	12.17	12.40	12.64	2.240
2.10	12.87	13.11	13.36	13.60	13.85	14.10	14.35	14.61	14.87	15.13	2.520
2.20	15.39	15.66	15.93	16.21	16.48	16.76	17.04	17.33	17.62	17.91	2.810
2.30	18.20	18.50	18.80	19.11	19.41	19.72	20.03	20.35	20.67	20.99	3.120
2.40	21.32	21.65	21.98	22.31	22.65	22.99	23.34	23.68	24.03	24.39	3.430
2.50	24.75	25.11	25.47	25.84	26.21	26.58	26.96	27.34	27.72	28.11	3.750
2.60	28.50	28.90	29.29	29.69	30.10	30.51	30.92	31.33	31.75	32.17	4.100
2.70	32.60	33.03	33.46	33.89	34.33	34.78	35.22	35.67	36.13	36.58	4.450
2.80	37.05	37.51*	37.82	38.13	38.44	38.75	39.07	39.38	39.70	40.02	3.280
2.90	40.33	40.65	40.97	41.29	41.62	41.94	42.27	42.59	42.92	43.25	3.250
3.00	43.58	43.91	44.24	44.57	44.90	45.24	45.57	45.91	46.25	46.59	3.350
3.10	46.93	47.27	47.61	47.96	48.30	48.65	48.99	49.34	49.69	50.04	3.460
3.20	50.39	50.74	51.10	51.45	51.81	52.16	52.52	52.88	53.24	53.60	3.570
3.30	53.96	54.32	54.69	55.05	55.42	55.78	56.15	56.52	56.89	57.26	3.680
3.40	57.64	58.01	58.38	58.76	59.14	59.51	59.89	60.27	60.65	61.04	3.780
3.50	61.42	61.80	62.19	62.57	62.96	63.35	63.74	64.13	64.52	64.91	3.890
3.60	65.31	65.70	66.10	66.49	66.89	67.29	67.69	68.09	68.49	68.90	3.990
3.70	69.30	69.70	70.11	70.52	70.93	71.33	71.74	72.16	72.57	72.98	4.100
3.80	73.40	73.81	74.23	74.64	75.06	75.48	75.90	76.32	76.75	77.17	4.200
3.90	77.60	78.02	78.45	78.88	79.30	79.73	80.16	80.60	81.03	81.46	4.300
4.00	81.90	82.33	82.77	83.21	83.65	84.09	84.53	84.97	85.41	85.86	4.400
4.10	86.30	86.75	87.19	87.64	88.09	88.54	88.99	89.45	89.90	90.35	4.510
4.20	90.81	91.26	91.72	92.18	92.64	93.10	93.56	94.02	94.48	94.95	4.600
4.30	95.41	95.88	96.35	96.81	97.28	97.75	98.22	98.70	99.17	99.64	4.690
4.40	100.1	100.6	101.1	101.6	102.0	102.5	103.0	103.5	104.0	104.4	4.800
4.50	104.9	105.4	105.9	106.4	106.9	107.4	107.9	108.3	108.8	109.3	4.900

Figure 2. Rating curve for USGS Cienega Creek stream gage 09484550

These measurements clearly show that there is water upstream and downstream of the weir when the USGS rating curve predicts that there is no flow over the gage (i.e., water level at the bottom of the weir). In fact, under those conditions, there is more than a 1.5 feet in the pool immediately upstream of the weir when no water is flowing over the weir. These measurements also indicate that the stage height of the USGS gage under predicts absolute water depth upstream of the weir.

Empirical data on wetted stream length

The Bureau of Land Management (BLM) has collected data on the length of wetted stream along Upper Cienega Creek, Empire Gulch, Mattie Canyon, and Gardner Canyon every June since 2006. These data indicate that during a span of 30 days of no flow at the USGS gage in the summer of 2010, approximately 7.1 miles of wetted stream length and 41 isolated pools were present in these drainages. The wetted stream length during this period was the second longest of the eight years that wet/dry data have been collected by the BLM. Clearly, the assumption by the October 2013 Model that Upper Cienega Creek and its tributaries are dry when there is no flow at the USGS gage is invalid, and the use of the term "dry days" is therefore inappropriate. Moreover, these data illustrate that not only are there remnant, isolated pools present in Upper Cienega Creek when the USGS gage predicts zero flow, but there are large portions of Upper Cienega Creek and its tributaries that are flowing.

Sensitivity of the October 2013 Model results to the assumption that Upper Cienega Creek and its tributaries are dry when the USGS gage predicts zero flow

To test how much control the assumption that no flow over the weir equates to no water in Upper Cienega Creek has on the results of the October 2013 Model, we adjusted the definition of "dry days" to reflect three scenarios:

1) The water depth at the USGS stream gage is equal to the stage measured of the USGS gage. This scenario will predict the drainage is dry when the USGS gage stage is predicted to be zero (***Table 4***). Note that no flow is predicted at the weir when the stage at the USGS gage measures 0.6 feet or less.
2) The water depth at the USGS stream gage is equal to the stage measure of the USGS gage plus 0.34 feet. This scenario takes into account the fact that the depth of the portion of the pool immediately upstream of the weir is 0.94 feet deep relative to the bottom of the weir. Thus the depth of that portion of the pool is 0.34 feet deeper than the stage height of the gage. This model scenario will predict that the drainage is dry when this portion of the pool immediately upstream of the weir is dry (***Table 5***).
3) The water depth at the USGS stream gage is equal to the stage measure of the USGS gage plus 1.07 feet. This scenario takes into account the fact that the depth of the portion of the pool immediately next to the gage is 1.67 feet deep relative to the bottom of the weir. Thus the depth of that portion of the pool is 1.07 feet deeper than the stage height of the gage. This model scenario will predict that the drainage is dry when this portion of the pool immediately next to the USGS gage is dry (***Table 6***).

Table 4. Number of "dry day"s per year predicted by the October 2013 Model when water depth is assumed to be the USGS stage height. Original data presented by SWCA (2013) are included in parentheses.

Period	Drainage	Number of Dry Days per Year (SWCA (2013) Values)				
		Minimum Predicted Drawdown Case	Best Fit[1]			Maximum Predicted Drawdown Case
			Model 1	Model 2	Model 3	
50 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (3)	0 (3)	0 (4)
	Empire Gulch Springs	0 (3)	0 (3)	0 (4)	0 (283)	357 (361)
	Gardner Canyon	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
150 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (3)	0 (32)	1 (313)
	Empire Gulch Springs	0 (3)	0 (32)	0 (32)	361 (363)	365
	Gardner Canyon	0 (3)	0 (3)	0 (3)	0 (4)	0 (146)
1,000 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (125)	3 (351)	3 (351)
	Empire Gulch Springs	360 (363)	363 (364)	364 (365)	365	365
	Gardner Canyon	0 (3)	0 (3)	0 (283)	359 (363)	359 (363)

[1] *SWCA (2013) does not match regional groundwater models to predictions of "dry days" in the October 2013 Model.*

Table 5. Number of "dry days" per year predicted by the October 2013 Model when water depth is assumed to be the USGS stage height plus 0.34 feet. Original data presented by SWCA (2013) are included in parentheses.

Period	**Drainage**	**Number of Dry Days per Year (SWCA (2013) Values)**				
		Minimum Predicted Drawdown Case	**Best Fit[1]**			**Maximum Predicted Drawdown Case**
			Model 1	**Model 2**	**Model 3**	
50 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (3)	0 (3)	0 (4)
	Empire Gulch Springs	0 (3)	0 (3)	0 (4)	0 (283)	354 (361)
	Gardner Canyon	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
150 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (3)	0 (32)	0 (313)
	Empire Gulch Springs	0 (3)	0 (3)	0 (32)	359 (363)	364 (365)
	Gardner Canyon	0 (3)	0 (32)	0 (3)	0 (4)	0 (146)
1,000 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (125)	0 (351)	0 (351)
	Empire Gulch Springs	358 (363)	363 (364)	364 (365)	365	365
	Gardner Canyon	0 (3)	0 (3)	0 (283)	357 (357)	357 (363)

[1] *SWCA (2013) does not match regional groundwater models to predictions of "dry days" in the October 2013 Model.*

Table 6. Number of "dry days" per year predicted by October 2013 Model when water depth is assumed to be the USGS stage height plus 1.07 feet. Original data presented by SWCA (2013) are included in parentheses.

Period	**Drainage**	**Number of Dry Days per Year (SWCA (2013) Values)**				
		Minimum Predicted Drawdown Case	**Best Fit[1]**			**Maximum Predicted Drawdown Case**
			Model 1	**Model 2**	**Model 3**	
50 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (3)	0 (3)	0 (4)
	Empire Gulch Springs	0 (3)	0 (3)	0 (4)	0 (283)	3 (361)
	Gardner Canyon	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
150 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (3)	0 (32)	0 (313)
	Empire Gulch Springs	0 (3)	0 (32)	0 (32)	353 (363)	364 (365)
	Gardner Canyon	0 (3)	0 (3)	0 (3)	0 (4)	0 (146)
1,000 years post mine closure	Upper Cienega Creek	0 (3)	0 (3)	0 (125)	0 (351)	0 (351)
	Empire Gulch Springs	349 (363)	360 (364)	363 (365)	365	365
	Gardner Canyon	0 (3)	0 (3)	0 (363)	313 (363)	313 (363)

[1] *SWCA (2013) does not match regional groundwater models to predictions of "dry days" in the October 2013 Model.*

These results illustrate that the October 2013 Model is highly sensitive to the false assumption that Upper Cienega Creek is dry when there is no flow at the USGS stream gage. In fact, the number of "dry days" predicted by SWCA (2013) in Upper Cienega Creek and Gardner Canyon is almost completely a consequence of this assumption. Upper Cienega Creek is predicted to have no "dry days" per year for all of the cases modeled using the empirical data described above with the exception of a few instances when the stage height is assumed to be the depth of the pool immediately upstream of the weir (***Tables 4, 5, and 6***). Even this scenario, however, is a conservative prediction of the number of "dry days", as empirical measurements of the depth of the pool upstream of the weir indicate that the pool is deeper than the USGS gage stage height.

Gardner Canyon is predicted to have no "dry days" under all scenarios except for a best fir and Maximum Drawdonw Case prediction at 1,000 years post mine closure.

The influence of the assumption on the number of "dry days" at Empire Gulch Springs is pronounced at

50 and 150 years post mine closure under all scenarios. The predicted number of "dry days" is zero at 50 years under all models with the exception of the Maximum Drawdown Case. At 150 years post closure, the predicted number of "dry days" is zero for all models except one best fit model and the Maximum Drawdown Case. For Empire Gulch Springs at 1,000 years post closure, the October 2013 Model is relatively insensitive to the false assumption that zero flow at the USGS gage equates to no surface water in Upper Cienega Creek.

Note that we do not provide a reanalysis of the October 2013 Model with respect to the number of "extreme low flow days". SWCA (2013) considers "extreme low flow days" to be those days that the depth of water at the USGS gage, as miscalculated by SWCA (2013), is less than 0.2 feet because, for every year of the available record of data at USGS stream gage 09484550, the gage experiences a water depth calculated by SWCA (2013) to be 0.2 feet, but not less than 0.2 feet. Although SWCA (2013) miscalculates water depth at the gage, this miscalculation only influences the absolute water depth, and not the frequency that the chosen water depth occurs. For example, if we assume that the stage height of the gage represents the depth of water at the weir, the depth of water on "extreme low flow days" is 0.8 feet, not 0.2 feet, but the stage height that represents 0.8 feet occurs every year while lower stage heights do not. As such, using the approach taken by SWCA (2013) to define "extreme low flow days," but using different scenarios to correct for absolute water depth at the weir do not influence the number of "extreme low flow days."

The biological interpretation of "extreme low flow days," however, is influenced by the false assumption made by SWCA (2013). After correction of water depth by using gage height or field collected data, the depth of water at the USGS gage during "extreme low flow days" as defined by SWCA (2013) is 0.8 to 1.87 feet. These water depths are experienced by native fish, and likely Gila topminnow (*Poeciliopsis occidentalis occidentalis*) and Gila chub (*Gila intermedia*), every year along Lower Cienega Creek. In fact, according to data collected by Pima Association of Governments (PAG), stream depths monitored monthly between 2009 and 2012 in Lower Cienega Creek never exceed 0.42 feet. Native fish are known to occur in these sections of Lower Cienega Creek, including Gila topminnow and Gila chub, suggesting that "extreme low flow days" as defined by SWCA (2013) are normally encountered by native fish.

2.3.2. The October 2013 Model Assumes that Surface Water Dynamics at the USGS gage are a Surrogate for Surface Water Dynamics along all of Upper Cienega Creek and its Tributaries

The October 2013 Model assumes that the depth of water at the USGS gage 09484550 on Upper Cienega Creek is a surrogate for the entire length of Upper Cienega Creek, Empire Gulch, and Gardner Canyon. In essence, SWCA (2013) assumes that changes in water depth at the USGS stream gage are mirrored by changes in water depth throughout Upper Cienega Creek, Empire Gulch, and Gardner Canyon. Thus a "dry day" at the gage, independent of the effect of drawdown from the mine, was considered by SWCA (2013) to be a "dry day" along the entire length of Upper Cienega Creek, Empire Gulch, and Gardner Canyon. No explicit test of this assumption was provided by SWCA (2013), although data from Tables 1 and 2, and Figure 4 of SWCA (2013) are cited as evidence that the depth of water at the USGS gage reasonably represents the conditions throughout Upper Cienega Creek and its tributaries. These data consist of water depths at other locations along Upper Cienega Creek.

For the locations with adequate sample size, we performed correlational analyses of these data used by SWCA (2013) to support the assumption that changes in water depth at the gage are a surrogate for changes in water depth in other portions of Upper Cienega Creek, Empire Gulch, and Gardner Canyon. Pearson's correlations of the data presented in Table 1 of SWCA (2013) indicate that there is no correlation between water depth at the USGS gage and elsewhere along Upper Cienega Creek (***Table 7***).

Table 7. Pearson'a Correlations of depth of water at the Upper Cienega Creek gage with other locations along Upper Cienega Creek

Location	Sample Size	Pearson's Correlation Coefficient[1]	*P*-value
Cienega Creek at Cedar Canyon	6	0.34	0.51
Cienega Creek at Stevenson Canyon	13	0.18	0.55
Cienega Creek below Pump Canyon	6	-0.192	0.72

[1] Note that Spearman's Rank Correlations of these data in some cases result in slightly stronger, albeit still nonsignificant correlations, but do not account for the magnitude of each data point.

The data collected by the BLM on wetted stream length along Upper Cienega Creek and its tributaries provide additional evidence that contradicts the assumption by SWCA (2013) that a “dry day” at the gage, independent of the effect of drawdown from the mine, is a “dry day” along the entirety of Upper Cienega Creek and its tributaries. If this assumption was true, there would be no wetted stream length along Upper Cienega Creek and its tributaries when no flow at the gage was recorded. The USGS gage measured no flow over the v-notch weir during 30 days in May and June 2010. The BLM wet/dry data indicate that approximately 7.1 miles of wetted stream length was present in Upper Cienega Creek and its tributaries during this period. The wetted stream length during this period was the second longest of the eight years that wet/dry data has been collected by the BLM. As such, the focus by SWCA (2013) on flow at the USGS gage as a means to calculate “dry days” along Upper Cienega Creek and its tributaries is not supported by the available data.

2.3.3. The October 2013 Model Overestimates the Impact of Drawdown on Upper Cienega Creek When Drawdown Occurs in Empire Gulch and Gardner Canyon

The October 2013 Model assumes that if the groundwater flow models predict that Empire Gulch and/or Gardner Canyon will experience a drawdown of 0.3 feet or greater, then an additional drawdown will occur at Upper Cienega Creek: and additional 0.05 feet for drawdown at Empire Gulch and an additional 0.13 feet for drawdown at Gardner Canyon. The assumption is that the reduced surface flow from Empire Gulch and Gardner Canyon will result in reduced depth of stream in Upper Cienega Creek in addition to the drawdown predicted by the regional groundwater flow models.

The October 2013 Model incorrectly assumes that drawdown at Upper Empire Gulch Spring and Gardner Canyon was not considered in the groundwater flow model predictions. The regional groundwater models' predicted drawdown at Upper Empire Gulch Spring and Gardner Canyon decreases the hydraulic gradient toward Upper Cienega Creek. The reduced hydraulic gradient results in the predicted decrease in streamflow in Upper Cienega Creek. Incorporating additional drawdown at the Cienega Creek gage from reduced streamflow at Empire Gulch and Gardner Canyon double counts the drawdown already accounted for by regional groundwater models.

Moreover, the wet/dry data collected by BLM indicate that Gardner Canyon is dry during June. Thus there can be no additional drawdown on Upper Cienega Creek during this period as a result of a reduction of stream flow from Gardner Canyon; Gardener Canyon is already dry under current conditions. The approach taken by SWCA (2013) implicitly assumes that even when Gardner Canyon is dry, additional drawdown at Upper Cienega Creek will occur. This assumption overinflates the effect of drawdown on Upper Cienega Creek.

The results of the October 2013 Model are sensitive to the double counting of the effect of tributaries on drawdown along Upper Cienega Creek. ***Table 8*** shows the number of “dry days” at Upper Cienega Creek predicted by the October 2013 Model if the drawdown due to tributary drawdown is removed from the model. The number in parenthesis is the value predicted by the October 2013 Model assuming additional drawdown.

Table 8. Number of “dry day”s per year predicted by the October 2013 Model for Upper Cienega Creek assuming no change in drawdown from reduced surface flow in Empire Gulch and Gardner Canyon.

Period	Number of Dry Days per Year (SWCA (2013) Values)				
	Minimum Drawdown Case	Best Fit[1]			Maximum Drawdown Case
		Model 1	Model 2	Model 3	
50 Years Post Mine Closure	3 (3)	3 (3)	3 (3)	3 (3)	3 (4)
150 Years Post Mine Closure	3 (3)	3 (3)	3 (3)	10 (32)	88 (313)
1,000 Years Post Mine Closure	3 (3)	3 (3)	4 (125)	283 (351)	283 (351)

[1] *SWCA (2013) does not match regional groundwater models to predictions of “dry days” in the October 2013 Model.*

2.3.4. The October 2013 Model Assumes that the Interaction between Groundwater and Surface Water is Governed by a 1:1 Ratio

The October 2013 Model assumes that predicted drawdown in the regional aquifer results in an equal drawdown in the depth of surface water in Upper Cienega Creek. ***Equations 1***, ***2***, and ***3*** in ***Section 2.2*** show that this is only possible if the hydraulic conductivity is infinite; there has to be some hydraulic gradient for there to be stream flow, and water depth in the channel will be related to stream flow and local channel conditions.

Groundwater discharge to Upper Empire Gulch Spring and to Cienega Creek occurs because the groundwater levels in the aquifer are higher than the spring elevation or streambed. Groundwater discharges to the spring or creek through bedrock fractures or through permeable alluvial sediments. If groundwater is the only water source and drawdown lowers the aquifer water level below the spring or stream elevation, groundwater will stop discharging to the surface and spring and stream flow will cease. However, if drawdown does not lower the water levels below the spring or streambed elevations they will continue to flow, but at lower flow rates. The flow rates decrease because the drawdown decreases the hydraulic gradients, which control how much groundwater discharges to the spring and stream. For a given flow rate of water in the drainage, the depth depends on channel slope, channel geometry, and channel roughness. Existing well data are used in ***Appendix A*** to illustrate this phenomenon.

The assumption substantially influences the results of the model. To inform how much the model is influenced by this assumption, we reran the October 2013 Model assuming that a drawdown of one foot in the regional aquifer equates to a 0.5 foot reduction in stream depth (***Table 9***) and assuming that a drawdown of one foot in the regional aquifer equates to a 0.1 foot reduction in stream depth (***Table 10***). All other variables were held constant. As ***Tables 9 and 10*** attest, the results of the number of "dry days" per year calculated by the October 2013 Model is highly sensitive to the unreasonable assumption that a one foot drawdown in the regional aquifer equates to a one foot drawdown in stream depth.

Table 9. Number of "dry days" per year predicted by the October 2013 Model with 1 foot of drawdown equal to 0.5 feet of surface water change.

Period	Drainage	Number of Dry Days per Year (SWCA (2013) Values)				
		Minimum Predicted Drawdown Case	Best Fit[1]			Maximum Predicted Drawdown Case
			Model 1	Model 2	Model 3	
50 years post mine closure	Upper Cienega Creek	3 (3)	3 (3)	3 (3)	3 (3)	3 (4)
	Empire Gulch Springs	3 (3)	3 (3)	3 (4)	10 (283)	354 (361)
	Gardner Canyon	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)
150 years post mine closure	Upper Cienega Creek	3 (3)	3 (3)	3 (3)	3 (32)	13 (313)
	Empire Gulch Springs	3 (3)	3 (32)	3 (32)	357 (363)	363 (365)
	Gardner Canyon	3 (3)	3 (3)	3 (3)	3 (4)	4 (146)
1,000 years post mine closure	Upper Cienega Creek	3 (3)	3 (3)	4 (125)	66 (351)	66 (351)
	Empire Gulch Springs	356 (363)	360 (364)	363 (365)	364 (365)	364 (365)
	Gardner Canyon	3 (3)	3 (3)	10 (283)	356 (363)	356 (363)

[1] *SWCA (2013) does not match regional groundwater models to predictions of "dry days" in the October 2013 Model.*

Table 10. Number of "dry days" per year predicted by the October 2013 Model with 1 foot of drawdown equal to 0.1 feet of surface water change.

Period	Drainage	Number of Dry Days per Year (SWCA (2013) Values)				
		Minimum Predicted Drawdown Case	Best Fit[1]			Maximum Predicted Drawdown Case
			Model 1	Model 2	Model 3	
50 years post mine closure	Upper Cienega Creek	3 (3)	3 (3)	3 (3)	3 (3)	3 (4)
	Empire Gulch Springs	3 (3)	3 (3)	3 (4)	3 (283)	4 (361)
	Gardner Canyon	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)
150 years post mine closure	Upper Cienega Creek	3 (3)	3 (3)	3 (3)	3 (32)	3 (313)
	Empire Gulch Springs	3 (3)	3 (32)	3 (32)	10 (363)	283 (365)
	Gardner Canyon	3 (3)	3 (3)	3 (3)	3 (4)	3 (146)
1,000 years post mine closure	Upper Cienega Creek	3 (3)	3 (3)	3 (125)	3 (351)	3 (351)
	Empire Gulch Springs	4 (363)	66 (364)	179 (365)	349 (365)	349 (365)
	Gardner Canyon	3 (3)	3 (3)	3 (283)	4 (363)	4 (363)

[1] *SWCA (2013) does not match regional groundwater models to predictions of "dry days" in the October 2013 Model.*

2.3.5. The October 2013 Model Uses Sensitivity Analyses to Bound the Analysis of Groundwater Effects on Upper Cienega Creek and its Tributaries

SWCA (2103) uses the sensitivity analyses from Montgomery & Associates (2010) and Tetra Tech (2010) to calculate possible minimum and maximum drawdown scenarios. During development of these regional groundwater models, parameter values were obtained during model calibration to find a "best fit" to historical data. These calibrated models provide the most reliable and accurate predictions. Sensitivity analyses were used to determine how sensitive the model predictions were to changes in parameter values. The sensitivity analyses were based on extreme parameter values that have a low probability of occurring and result in a poor model fit to the observed data. Impact predictions using the extreme sensitivity analysis parameter values are less reliable and speculative due to the model being out of calibration.

The sensitivity analyses performed on the regional groundwater models were developed to provide a maximum range of potential impacts for the EIS. The predictions were not intended to imply there was a reasonable potential for the impacts to occur. The use of these predictions as likely to occur is an inappropriate use of the modeling results.

3. AN ALTERNATIVE MODEL TO INFORM POTENTIAL IMPACTS TO UPPER CIENEGA CREEK AND ITS TRIBUTARIES

Because the October 2013 Model that relies on assumptions that are not supported by available data or theory, but have substantial influence on the results of their analysis, we developed an alternative approach to inform the risk of Upper Cienega Creek and its tributaries going dry. This model is based on a combination of empirical data collected by the BLM on wetted stream length along Upper Cienega Creek and its tributaries and predictions from two of the regional groundwater models.

Briefly, using the wet/dry data provided by the BLM, we fit several distributions to these data. We used the two best fit distributions to calculate the probability that over the next 176 (150 years post mining) and 1,026 years (1,000 years post-mining) that Upper Cienega Creek and its tributaries would all be dry. By using empirical data to calculate the risk of Upper Cienega Creek going dry, we avoid many of the problematic assumptions that plague the October 2013 Model, and rely on fewer assumptions.

Below we describe the methods used to develop this model and the results of a suite of analyses. Note that a similar approach can be taken to inform impacts of drawdown on Lower Cienega Creek using predicted reduction in cfs, stream gage data, and observed wetted stream length specific to Lower Cienega Creek.

3.1. METHODS

Table 11 shows the measured wetted stream length along Upper Cienega Creek, Mattie Canyon, Lower Empire Gulch, and Lower Gardner Canyon, and number of pools each year provided by the BLM. These data were collected each summer in June from 2006 through 2013 such that the wetted stream length is not likely to have been affected by surface flows and the resulting values likely represent the wetted length at or near its annual minimum.

For the purposes of this analysis, we did not differentiate between wetted steam length along Upper Cienega Creek, Lower Empire Gulch, Mattie Canyon, and lower Gardner Canyon. These drainages are all predicted to experience similar, small drawdowns (Engineering Analytics 2012, Montgomery & Associates 2012). We excluded Empire Gulch Springs from the analysis because this location is predicted to have greater effects than the drainages listed above. Both the Final Environmental Impact Statement and Biological Opinion for the Rosemont Copper Project have recognized that substantial effect of drawdown at Empire Gulch Springs is possible, and we do not address those effects here.

Table 11. Wetted stream length collect by the BLM along Upper Cienega Creek, Empire Gulch, and Gardner Canyon

Date	Wetted Stream Length (miles)	Number of Isolated Pools
June 2006[1]	6.0	19
June 2007[1]	6.0	23
June 2008[1]	5.5	22
June 13, 2009	8.1	42
June 12, 2010	7.1	41
June 11, 2011	7.1	37
June 14, 2012	4.8	31
June 22, 2013	4.7	10

[1] *Date not reported.*

The approach developed here is based on fitting the wetted stream length to a common distribution to calculate the probability that wetted stream length will reduce to zero. For the eight data points presented in ***Table 11***, the mean stream length is approximately 6.2 miles, and the standard deviation is approximately 1.2 miles. Because of low sample size, and thus lower power of the Anderson-Darling test, we fit the data to several distributions (***Table 12***). This allowed for a transparent evaluation of which distribution was an appropriate fit to the distribution of wetted stream length. Generally, the higher the probability-value of the test, or the smaller the test statistic, the more likely that the sample is from the given distribution.

Table 12. Results of Anderson-Darling test of wetted stream length data.

Distribution	Anderson-Darling Test Statistic[1]	P-value
Lognormal	0.249	0.64
Normal	0.262	0.60
Gamma	0.288	0.25
Weibull	0.306	0.25
Smallest Extreme Value	0.358	0.25
Exponential	2.499	0.003

[1] *Note that the smaller the Anderson-Darling test statistic, the better the fit of the data to that distribution.*

Based on the Anderson-Darling test, the normal and lognormal distributions provide the best fit to the wetted stream length data; all other distributions tested produced a worse fit to the observed data. ***Figure 3*** shows probability plots for the normal and lognormal distributions.

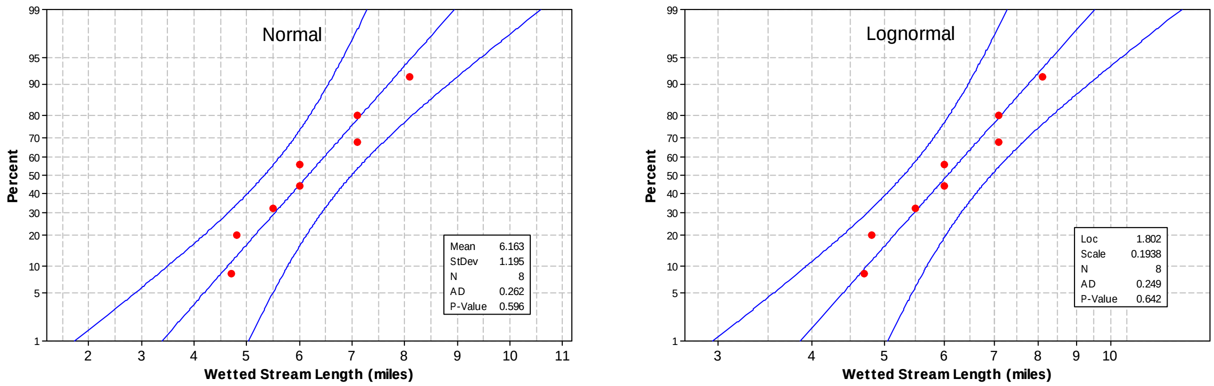


Figure 3. Probability plots with 95% confidence limits for normal and lognormal distributions.

Figure 4 is a comparison of the normal and lognormal probability density functions based on these data. ***Figure 5*** is the cumulative probability function which is equal to ***Equation 4*** for the normal distribution and ***Equation 5*** for the lognormal distribution, where $p(x)$ is equal to the normal or lognormal probability distribution function shown in ***Figure 4***.

$$P(X \leq x) = \int_{-\infty}^{x} p(x)\mathrm{d}x \tag{4}$$

$$P(X \leq x) = \int_{0}^{x} p(x)\mathrm{d}x \tag{5}$$

In other words, ***Figure 5*** is equal to the area under the curve from $-\infty$ to *x* (0 to *x* for lognormal), where *x* is the wetted stream length on the *x*-axis. For the models that are described in detail below, the probabilities are calculated from the left end of the probability density functions. Notice how the normal and lognormal cumulative probability curves are different at certain wetted stream lengths; this results in different predictions for the two distributions. We analyzed both of these distributions to illustrate the range of results produced from the two distributions that are the best fit to the data.

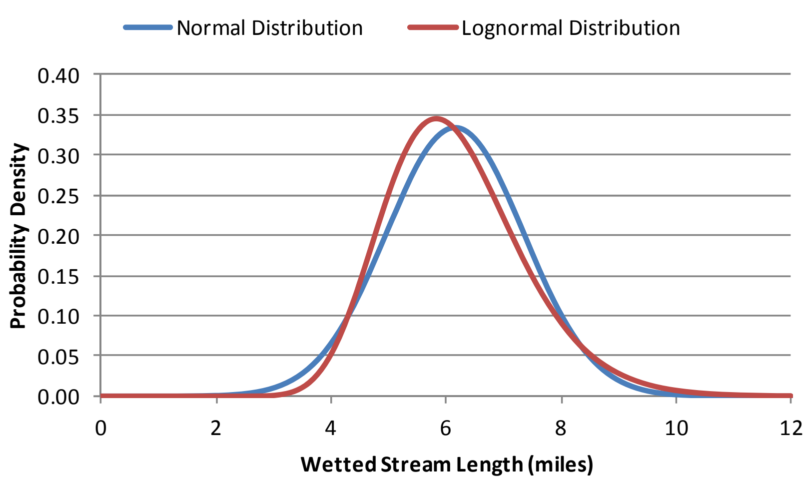


Figure 4. Probability density distribution for the normal and lognormal distributions fit to the BLM stream length data.

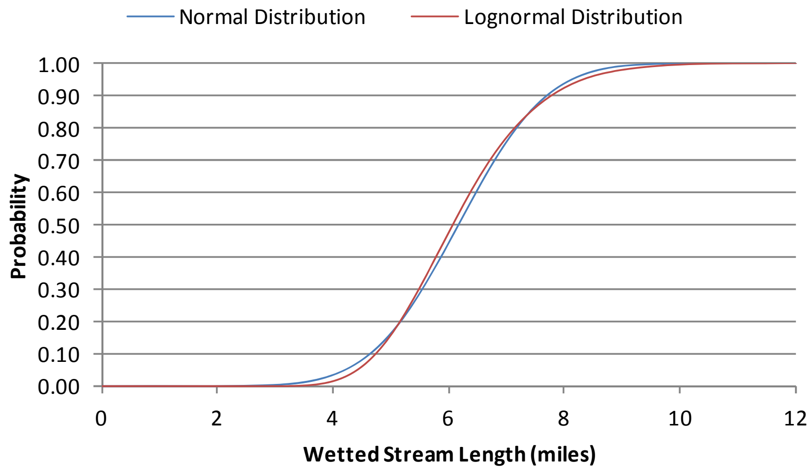


Figure 5. Cumulative probability function for the normal and lognormal distributions fit to the BLM stream length data.

In the sections that follow, we analyze three scenarios[1]:

1) the mine is not developed (the base case),
2) the mine is developed and the effects are predicted by the Montgomery & Associates (2010) regional groundwater model, and
3) the mine is developed and the effects are predicted by the Tetra Tech (2010) regional groundwater model.

For the base case, the probability density functions are the same each year. For the other scenarios, the probability density functions move to the left relative to the x-axis as the mean stream length is reduced (the lognormal distribution changes shape slightly as the mean is reduced so that the right endpoint is always zero). A probability equal to $1 - P(X \leq x)$, is calculated for each year based on the mean wetted stream length for the year, and the product of all years is equal to the probability that the wetted stream length will be greater than x for *all* of the 176 or 1,026 years analyzed, where x is equal to 0 miles or 1 mile of wetted stream length.

In addition, we completed a simulation for each scenario to determine the likelihood of multiple years with wetted stream length less than 1 mile. We chose 1 mile as a metric to be analyzed because it provides insight into the probability the wetted stream length is reduced to very short lengths, but not to zero.

It is important to realize that this approach analyzes wetted stream length only during the driest part of the year, the month of June. As such, the analyses that follow examine the potential effects of drawdown from the mine at the extreme that aquatic organisms experience. This extreme does not persist year round. For example, if the models described below conclude that there is some probability that wetted stream length along Upper Cienega Creek will be less than 1 mile, this does not mean that models predict that wetted stream will be 1 mile or less for the *entire* year. Wetted stream length is expected to be longer during months other than June.

[1] The paucity of data and results provided by Meyers (2010) precludes its inclusion in this analysis.

3.1.1. Base Case

The base case represents the possible fluctuations in wetted stream length in the month of June without the effects of the mine. ***Equation 6*** can be used to calculate the probability that wetted stream length will be greater than x miles over the entire 176 or 1,026 year period. The $P_i(X \leq x)$ is the probability that wetted stream length will be less than or equal to x miles during year i, given the sample mean and standard deviation for year i, and the normal or lognormal distribution. For the base case, the probability is the same for each year. For the lognormal distribution, the probability that the wetted stream length is less than or equal to zero is zero for all cases.

$$P(X > x)_{years} = \prod_{i=1}^{years} (1 - P_i(X \leq x)) \tag{6}$$

For the base case, the mean and standard deviation are assumed to be constant for the 176 or 1,026 year period, and ***Equation 6*** can be simplified to ***Equation 7***. For the models using data from Montgomery & Associates (2010) and Tetra Tech (2010), ***Equation 6*** is used to account for the predicted change to mean wetted stream length each year as a result of groundwater drawdown.

$$P(X > x)_{years} = \left(1 - P(X \leq x)\right)^{years} \tag{7}$$

3.1.2. Montgomery & Associates Model

Montgomery &Associates (2010) includes predictions of the reduction in wetted stream length for three time periods as shown in ***Table 13***. For our analysis, we assumed that the predicted reduction in wetted stream length represents an average reduction, and that wetted stream length would vary according to the normal or lognormal distribution calculated from the wetted stream lengths in ***Table 11***.

Table 13. Reduction in wetted stream length predicted by Montgomery and Associates groundwater hydrology model (Montgomery and Associates 2010).

Year Post-closure	Model Year	Predicted Reduction in Wetted Stream Length (miles)
50	76	0.0
150	176	0.0
1,000	1,026	0.16

The reduction in mean wetted stream length was modelled two ways:

1. Linear Function – the reduction in stream length varies linearly between model year 176 (150 years post closure) and model year 1,026 (1,000 years post closure).
2. Step Function – the reduction in stream length is the same (0.16 miles) between model year 176 (150 years post closure) and model year 1,026 (1,000 years post closure).

The latter approach was developed to account for, in part, a nonlinear drawdown curve whereby drawdown increases rapidly following the cessation of mining and then asymptotes as the model approaches 1,026 years. ***Figure 6*** shows the mean wetted stream length for each year in the model. ***Equation 6*** was used to calculate probabilities, but the mean wetted stream length for each year was reduced by the amount presented in ***Table 13***. For the lognormal distribution, the variance of the distribution increases as the mean decreases; this adjustment was included in the lognormal models.

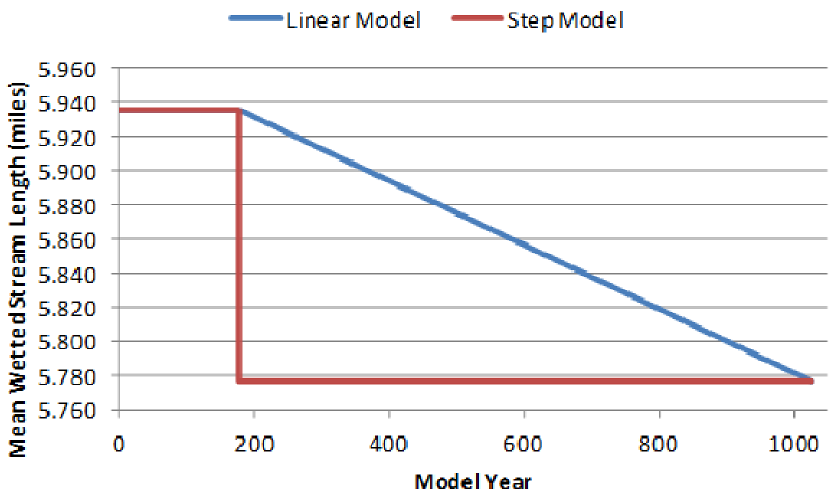


Figure 6. Mean wetted stream length by Year for Montgomery and Associates model.

3.1.3. Tetra Tech Model

Tetra Tech (2010) does not include predictions of the reduction in wetted stream length, but does include predictions of a decrease in flow in Upper Cienega Creek. To translate the predicted reduction in flow to a reduction in wetted stream length, it was necessary to find a relationship between flow and stream length. Flow at the USGS gage 09484550 on Upper Cienega Creek was correlated with the BLM wetted stream lengths using average daily flow across several time periods preceding the date of wet/dry mapping. ***Figure 7*** depicts the Pearson's correlation coefficient and *P*-value of the coefficient for the correlation between wetted stream length and average daily flow ranging from the day that wet/dry mapping occurred to 365 days prior to the day that wet/dry mapping occurred. The date that wet/dry mapping occurred in 2006, 2007, and 2008, was not provided by BLM, so these correlations assume that the mapping was conducted on June 15th of those years. Average daily flow from the 170 days preceding the wetted stream length measurement (***Table 14***) resulted in the highest correlation with wetted stream length (Pearson's r = 0.66, P = 0.115, ***Figure 7***). A linear regression of the 170-day relationship resulted in a slope of approximately 4.35 miles of wetted stream length per 1 cfs change in flow ($\hat{\beta}$ = 4.18, P = 0.115, R^2 = 0.36); i.e., a decrease in one cfs at the USGS gage is related to a 4.18 mile reduction in wetted stream length.

It should be noted that he lowest correlation occurred using the average flow from the preceding 30 days. These results indicate that long term (previous 170 days) precipitation is a significant influence on stream flow. The low correlation during June when precipitation is the lowest indicates that groundwater does not have a significant influence on stream flow.

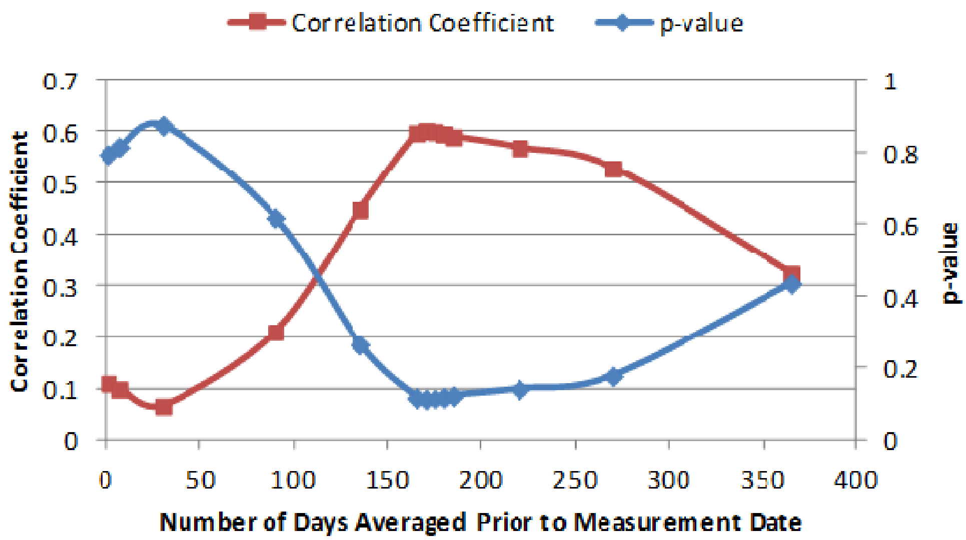


Figure 7. Correlation between flow and wetted stream length as a function of averaging period.

Table 14. BLM wetted stream length versus average flow for previous 170 days.

Date of Wetted Stream Length Measurement	Wetted Stream Length (miles)	Average Flow for Previous 170 days (USGS Gage 09484550) (cfs)
June 15, 2006[1]	5.85	0.64
June 15, 2007[1]	5.80	0.71
June 15, 2008[1]	5.23	0.73
June 13, 2009	7.84	0.99
June 12, 2010	6.84	1.16
June 11, 2011	6.84	0.83
June 14, 2012	4.60	0.81
June 22, 2013	4.50	0.75

[1] *Measurement date not reported; assumed June 15 for model.*

Table 15 shows the reduction in flow predicted by Tetra Tech (2010) for Upper Cienega Creek and the reduction in stream length predicted by the relationship between flow and stream length defined above. As with the Montgomery & Associates (2010) model described above, the reduction in mean wetted stream length was modeled two ways:

1) Linear Function – the reduction in stream length varies linearly between model year 76 (50 years post closure) and model year 1,026 (1,000 years post closure).

2) Step Function – the reduction in stream length is the same (0.334 miles) between model year 76 (50 years post closure) and model year 1,026 (1,000 years post closure).

Equation 6 was used to calculate probabilities, but for the Tetra Tech model, the mean wetted stream length for each year was reduced by the amount shown in ***Table 15***. ***Figure 8*** shows the mean wetted stream length for each year in the model. For the lognormal distribution, the variance of the distribution increases as the mean decreases; this adjustment was included in the lognormal models.

Table 15. Reduction in flow and wetted stream length predicted by the Tetra Tech groundwater hydrology model (Tetra Tech 2010).

Year Post-closure	Model Year	Predicted Reduction in Flow (cfs)	Predicted Reduction in Wetted Stream Length (miles)
50	76	0.0	0.0
1,000	1,026	0.08	0.334[1]

[1] *Based on 4.35 miles of wetted stream length per one cfs change in flow.*

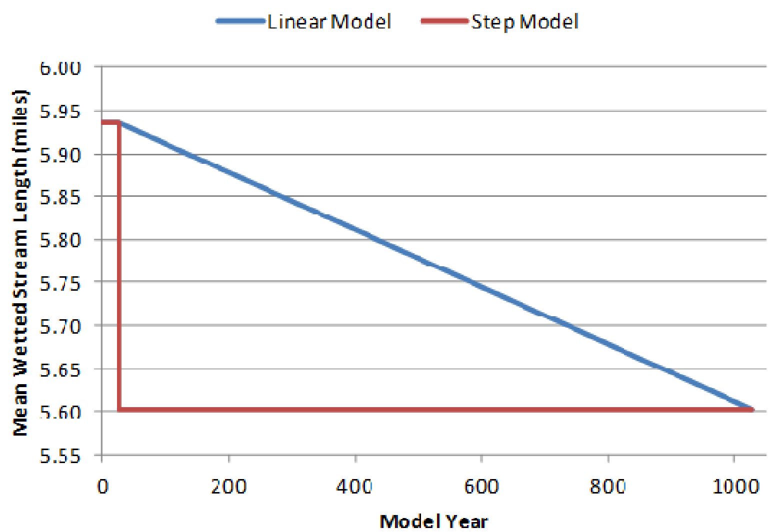


Figure 8. Mean wetted stream length by Year for Tetra Tech model.

3.1.4. Simulations of Wetted Stream Length

In addition to calculating probabilities that the wetted length would always be greater than 0 miles or 1 mile for the 176 and 1,026 year periods, we developed a simulation to examine further instances that wetted stream length would be less than 1 mile. The simulation used random numbers generated from the normal and lognormal distributions described above and the mean wetted stream lengths as a function of time as shown in ***Figures 6*** and ***8***. The simulation was run 10,000 times for each scenario described above (base case, Montgomery & Associates model, and Tetra Tech model) to determine how many iterations in the simulations had at least one year with less than 1 mile of wetted stream length after 176 or 1,026 years.

3.2. Results

Table 16 shows the probabilities that Upper Cienega Creek will not go completely dry (0 miles), and that the wetted length will remain greater than 1 mile every year for a 176 year and for a 1,026 year period for each scenario modeled using the normal distribution. Based on the results in ***Table 16***, the probability of the drainage going completely dry one or more times over a 176 or 1,026 year period is extremely small, less than 0.01% and 0.06%, respectively. The probability that the wetted length never drops below 1 mile is greater than 99% and 97% for a 176 and 1,026 year period, respectively.

Table 16. Probability Upper Cienega Creek wetted length will be greater than indicated length during 150 year and 1,026 year periods assuming normal distribution.

Model	Probability Wetted Length is Greater than *x* for Period *t*.			
	t = 150 years post closure		*t* = 1,000 years post closure	
	x = 0 miles	*x* = 1 mile	*x* = 0 miles	*x* = 1 mile
Base Case	100.00%	99.78%	99.99%	99.20%
Montgomery and Associates (Linear Model)	100.00%	99.78%	99.98%	98.96%
Montgomery and Associates (Step Model)	100.00%	99.78%	99.98%	98.66%
Tetra Tech (Linear Model)	100.00%	99.76%	99.97%	98.40%
Tetra Tech (Step Model)	99.99%	99.32%	99.94%	97.21%

When the lognormal distribution is used for models there is zero probability that any scenario will result in the drying of Upper Cienega Creek[2] or the reduction in wetted stream length to less than 1 mile.

Table 17 shows the results of the simulation described in ***Section 3.1.4***., using the normal distribution. The events tallied in ***Table 17*** result from a year in which an iteration of the simulation predicts a wetted stream length less than 1 mile. In the iterations that simulated an event, every scenario has two events occurring in the same iteration (2 years out of 1,026 years: 10,000 iterations). There were no cases of 3 or more events occurring in the same simulation iteration over either a 176 or 1,026 year period. Using the lognormal distribution results in zero events for all scenarios. These results indicate that not only is there an extremely low probability that Upper Cienega Creek will dry to less than 1 mile of wetted stream over a 176 or 1,026 year period, but even when it is simulated to do so, it occurs only once and very rarely twice.

Table 17. Number of times that simulation predicted a wetted stream length less than 1 mile in 10,000 iterations – based on a normal distribution.

Model	Number of iterations with an event[1] occurring *x* times out of 10,000 iterations.			
	x = 1 time		*x* = 2 times	
	176 year period	1,026 year period	176 year period	1,026 year period
Base Case	13	83	0	1
Montgomery and Associates (Linear Model)	13	100	0	1
Montgomery and Associates (Step Model)	13	125	0	1
Tetra Tech (Linear Model)	16	147	0	1
Tetra Tech (Step Model)	61	246	0	3

[1] An event is a year with a predicted wetted stream length less than 1 mile.

3.3. ACCOUNTING FOR CLIMATE CHANGE

For all scenarios modeled above, the analysis assumed that the only reductions to wetted stream length were those resulting from mining activities. As such, mean wetted stream length was constant for the base case. Consequently, those models assumed no reduction in wetted stream length due to climate change. To inform the potential effects of the mine, while taking into account the potential effects of climate change, we adjusted the models described above to account for a reduction in stream flow of 10% to 40% in the Southwest over the next 100 years due to climate change. The reduction in stream flow due to

[2] Note that by definition, a value of zero can never occur using a lognormal distribution.

climate change was derived from a review of the available literature (Hungate and Koch 2012). Below we describe the methods for incorporating climate change into our models and the results of these models.

3.3.1. Methods – Accounting for Climate Change

To account for the 10% to 40% reduction in stream flow in a model developed around wetted stream length, three questions need to be answered:

- What is the pattern of the reduction in stream flow over time?
- What base flow should be used to calculate the change in stream flow?
- What is the conversion from reduction in stream flow to reduction in wetted length?

Pattern of Stream Flow over Time: Since the predicted reductions in wetted stream flow occur over the next 100 years, and the models look at reduction in wetted stream length over the next 176 to 1,026 years, we assumed that the effect of reduced stream flow due to climate change was zero at year zero, and that the effect changed linearly to 100 years where it reached its maximum value. Because the available data do not provide predictions of reductions in stream flow past 100 years, we assumed that the effect of climate change on stream flow stayed at its maximum value for years 100 to 1,026. We ran separate models for each scenario with a reduction in stream flow due to climate change of 10% and 40%.

Base Flow: Because our models are based on wetted stream length data collected in June, the average June flow rate was used as the base flow. The average base flow used in this model is based on the average daily flow from the USGS Cienega Creek gage number 09484550 from June 2002 through June 2013. The average flow for this period was 0.268 cfs. Thus we assumed that the effect of climate change reduced stream flow by 0.0268 cfs (10% of 0.268 cfs) or 0.1072 cfs (40% of 0.268 cfs).

Conversion of reduction in stream flow to reduction in wetted length: To translate the effect of climate change on stream flow to wetted stream length, we used the model developed and explained in ***Section 3.1.3***. that related wetted stream length to the daily average flow at the USGS stream gage on Upper Cienega Creek over the 170 days prior to the measurement of wetted stream length. ***Figure 9*** shows the reduction in stream length per year due to climate change based on these assumptions.

Base Case

Figure 10 shows the mean wetted stream length by model year assuming 10% and 40% reductions in stream flow.

Montgomery and Associates Model

Figure 11 shows the mean wetted stream length by year used in the model using the results of the Montgomery & Associates (2010), assuming a linear and step change in mean wetted stream length, and including the 10% and 40% reduction in stream flow to account for the predicted effect of climate change on stream flow.

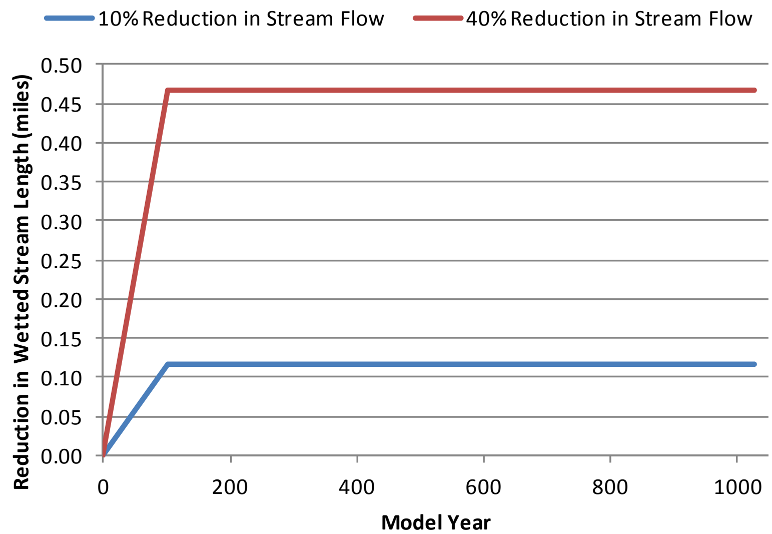


Figure 9. Reduction in mean wetted stream length assuming 10% and 40% reductions in stream flow.

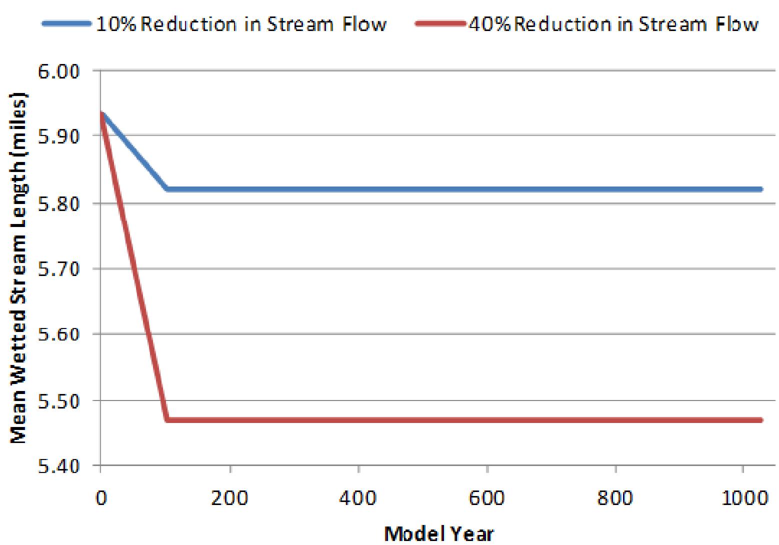


Figure 10. Mean wetted stream length by Year for Base Case with climate change assumptions.

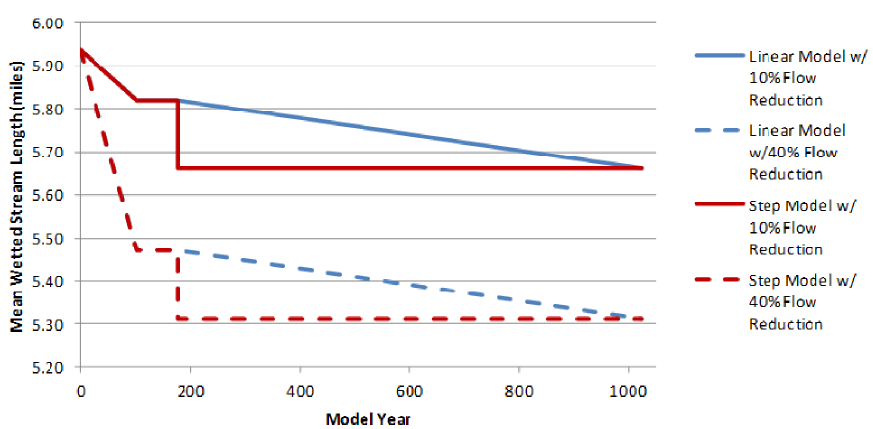


Figure 11. Mean wetted stream length by Year for Montgomery and Associates model with climate change assumptions.

Tetra Tech Model

Figure 12 shows the mean wetted stream length by year used in the model using the results of the Tetra Tech (2010), the relationship between reduced flow and reduced wetted stream length described in ***Section 3.1.3***, assuming a linear and step change in mean wetted stream length, and including the 10% and 40% reduction in stream flow to account for the predicted effect of climate change on stream flow.

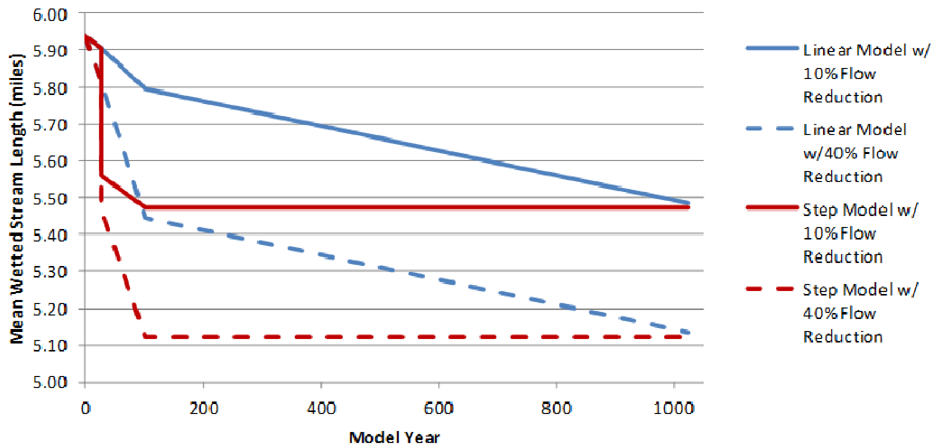


Figure 12. Mean wetted stream length by Year for Tetra Tech model with climate change assumptions.

3.3.2. Results – Accounting for Climate Change

10% Reduction in Stream Flow

Table 18 shows the calculated probabilities of the wetted stream length being greater than 0 miles or 1 mile in *all* years of a 176 or 1,026 year period for each scenario while accounting for a predicted effect of climate change of a 10% reduction in stream flow. The probability that Upper Cienega Creek and its tributaries will go dry is exceedingly small (< 0.03% to 0.14%) under all scenarios modelled. The effect of climate change does result in a decrease in the probability that wetted stream length in Upper Cienega Creek will always be greater than 1 mile, but the effect of the drawdown from the mine is small at both 176 years (a decrease of 0% to 0.63%) and 1,026 years (a decrease of 0.58% to 4.4%).

Table 18. Probability Upper Cienega Creek wetted length will be greater than indicated length during 176 year and 1,026 year periods assuming normal distribution and a 10% reduction in stream flow due to climate change.

Model	Probability Wetted Length is Greater than *x* for Period *t*.			
	t = 150 years post closure		*t* = 1,000 years post closure	
	x = 0 miles	*x* = 1 mile	*x* = 0 miles	*x* = 1 mile
Base Case	99.99%	99.69%	99.97%	98.04%
Montgomery and Associates (Linear Model)	99.99%	99.69%	99.95%	97.46%
Montgomery and Associates (Step Model)	99.99%	99.69%	99.94%	96.76%
Tetra Tech (Linear Model)	99.99%	99.66%	99.92%	96.24%
Tetra Tech (Step Model)	99.98%	99.06%	99.86%	93.74%

When the lognormal distribution is used for models there is zero probability that any scenario will result in the drying of Upper Cienega Creek[3] or the reduction in wetted stream length to less than 1 mile.

Table 19 shows the results of the simulation described in ***Section 3.1.4***., using the normal distribution, plus a 10% reduction in stream flow at 100 years as a result of climate change. The events tallied in ***Table 19*** result from a year in which an iteration of the simulation predicts a wetted stream length less than 1 mile. In the iterations that simulated an event, the overwhelming majority simulate only a single year out of the 176 or 1,026 year period that would result in a wetted stream length less than 1 mile. There were no cases of 3 or more events occurring in the same simulation iteration. Using the lognormal distribution, no events are predicted in any scenario.

These results indicate that not only is there a low probability that Upper Cienega Creek and its tributaries will dry to less than 1 mile of wetted stream over a 176 or 1,026 year period, but even when it is simulated to do so, it occurs only once and very rarely twice, even when a predicted effect of 10% reduction in stream flow due to climate change is included in models.

Table 19. Number of times that simulation predicted a wetted stream length less than 1 mile in 10,000 iterations – based on a normal distribution and assuming a 10% reduction in stream flow due to climate change.

Model	Number of iterations with an event[1] occurring *x* times out of 10,000 iterations.			
	***x* = 1 time**		***x* = 2 times**	
	176 year period	**1,026 year period**	**176 year period**	**1,026 year period**
Base Case	23	115	0	1
Montgomery and Associates (Linear Model)	23	144	0	1
Montgomery and Associates (Step Model)	23	182	0	2
Tetra Tech (Linear Model)	30	209	0	1
Tetra Tech (Step Model)	82	364	0	10

[1] *An event is a year with a predicted wetted stream length less than 1 mile*

40% Reduction in Stream Flow

Table 20 shows the calculated probability of wetted stream length being greater than 0 miles or one mile in *all* years of a 176 or 1,026 year period for each scenario while accounting for a predicted effect of climate change of a 40% reduction in stream flow. The probability that Upper Cienega Creek and its tributaries will go dry is exceedingly small (0.15% to 0.57%) under all scenarios modelled. The effect of climate change does result in a decrease in the probability that wetted stream length in Upper Cienega Creek and its tributaries will always be greater than 1 mile, but the effect of the drawdown from the mine is small at 176 years (a decrease of 0% to 1.68%), and relatively larger for some scenarios at 1,026 years (a decrease of 1.69% to 11.95%).

[3] Note that by definition, a value of zero can never occur using a lognormal distribution.

Table 20. Probability Upper Cienega Creek wetted length will be greater than indicated length during 150 year and 1,026 year periods assuming normal distribution and a 40% reduction in stream flow due to climate change.

Model	Probability Wetted Length is Greater than *x* for Period *t*.			
	t = 150 years post closure		*t* = 1,000 years post closure	
	x = 0 miles	*x* = 1 mile	*x* = 0 miles	*x* = 1 mile
Base Case	99.98%	99.15%	99.85%	93.54%
Montgomery and Associates (Linear Model)	99.98%	99.15%	99.80%	91.75%
Montgomery and Associates (Step Model)	99.98%	99.14%	99.73%	89.68%
Tetra Tech (Linear Model)	99.98%	99.06%	99.68%	88.24%
Tetra Tech (Step Model)	99.93%	97.47%	99.43%	81.59%

When the lognormal distribution is used for models there is zero probability that any scenario will result in the drying of Upper Cienega Creek[4] or the reduction in wetted stream length to less than 1 mile.

Table 21 shows the results of the simulation described in ***Section 3.1.4***., using the normal distribution, while including a 40% reduction in stream flow at 100 years as a result of climate change. The events tallied in ***Table 21*** result from a year in which an iteration of the simulation predicts a wetted stream length less than 1 mile. In the iterations that simulated an event, the overwhelming majority simulate only a single year out of 176 or 1,026 years that would result in a wetted stream length less than 1 mile. After 1,026 years, all scenarios included an iteration that simulated 2 years that wetted stream length was less than 1 mile. Using the lognormal distribution, no events are predicted under any scenario.

Table 21. Number of times that simulation predicted a wetted stream length less than 1 mile in 10,000 iterations – based on a normal distribution and assuming a reduction in stream flow of 40% due to climate change.

Model	Number of iterations with an event[1] occurring *x* times out of 10,000 iterations.					
	x = 1 time		*x* = 2 times		*x* =3 times	
	176 year period	1,026 year period	176 year period	1,026 year period	176 year period	1,026 year period
Base Case	69	371	0	10	0	0
Montgomery and Associates (Linear Model)	69	475	0	15	0	0
Montgomery and Associates (Step Model)	69	573	0	21	0	0
Tetra Tech (Linear Model)	77	663	0	29	0	0
Tetra Tech (Step Model)	237	1,046	2	63	0	1

[1] *An event is a year with a predicted wetted stream length less than 1 mile.*

4. CONCLUSION

Our review of the October 2013 Model identified several key assumptions that are not supported by available data or do not follow the physical processes that govern groundwater dynamics. We also illustrated how these assumptions have considerable influence over the results of the SWCA (2013) model. In fact, certain assumptions have almost complete control over the results of the analysis. As such, although the October 2013 Model does inform the range of potential effects of groundwater drawdown on Upper Cienega Creek, its reliance on numerous unsupported and untested assumptions that have high

[4] Note that by definition, a value of zero can never occur using a lognormal distribution.

influence on model findings results in an overly speculative analysis that is not appropriate for use in Section 7 consultation for the Rosemont Copper Project.

We have proposed an alternative model that is based on empirical observations of the extent of wetted stream length in Upper Cienega Creek and its tributary drainages. This approach avoids some of the assumptions that are problematic in the October 2013 Model, and provides estimated probabilities that Upper Cienega Creek, its tributaries, and Lower Cienega Creek will dry completely, or to such an extent that less than 1 mile of wetted stream length will remain. This approach also allows for the explicit inclusion of the potential effects of climate change on stream flow into our analysis.

Apart from the assumptions inherent in the regional groundwater models from which effects of drawdown on stream flow were obtained, our analysis relies on two major assumptions:

1) wetted stream length along Upper Cienega Creek and its tributaries in June follows a known distribution, and
2) stream flow at the USGS stream gage on Upper Cienega Creek is related to wetted stream length.

To inform the reasonableness of the first assumption, we tested numerous distributions against the wetted stream length data. Two distributions fit the data the best, and we performed analyses using both of these distributions to inform the range of predicted results from best fit distributions. To inform the second assumption, we performed a serial correlational analysis to obtain the best relationship between stream flow and wetted stream length. As such, the key assumptions of our analysis are explicitly addressed, resulting in a reasonable analysis to inform the potential effects of groundwater drawdown on Upper Cienega Creek and its tributaries.

The results of our analyses indicate that the risk that Upper Cienega Creek and its tributaries will be completely dry, or dry to less than 1 mile, as a result of drawdown from the mine is small, and under most scenarios highly improbable.

This same approach can be taken to inform the potential effects of groundwater drawdown on Lower Cienega Creek using gage data and wetted stream length specific to Lower Cienega Creek.

5. LITERATURE CITED

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APPENDIX A

GROUNDWATER CROSS-
SECTION ACROSS THE
UPPER CIENEGA CREEK AREA

Technical Memorandum

To: File

From: Karen Herther
Rosemont Copper Company

Subject: **Groundwater Cross-Section Across the Upper Cienega Creek Area**

Date: May 19, 2014

This Technical Memorandum was prepared to describe and present specific well data as it relates to stream flow in Upper Cienega Creek and the hydraulic gradients between those wells and the stream. This data is being presented in response to SWCA Environmental Consultants (SWCA) model/analysis, developed in October 2013, which assumed a linear 1:1 ratio of groundwater drawdown in the regional aquifer and a decrease in stream flow in Upper Cienega Creek.

1.0 BACKGROUND

Impacts to riparian areas, endangered species, and stream flow in Cienega Creek and Empire Gulch, potentially resulting from groundwater drawdown due to the Rosemont Copper Project (Project), are currently being analyzed by the U.S. Forest Service and U.S. Fish and Wildlife Service. Data being reviewed by the agencies include: the results from three groundwater flow models (Montgomery & Associates 2010; Tetra Tech 2010; and Myers 2008), publicly-available well data (Arizona Department of Water Resources [ADWR], Pima Association of Governments [PAG], and others), stream gage flow data recorded by the U.S. Geological Survey (USGS) stream gage (No. 09484550), and recently-provided U.S. Bureau of Land Management (BLM) groundwater level data, weir measurements and wet/dry stream flow data.

All three groundwater flow models predicted negligible and immeasurable impacts in Cienega Creek due to groundwater drawdown (from mine pit de-watering) at least 50 years after the cessation of mining operations. At 1,000 years after mine closure, the most conservative model (Tetra Tech 2010) predicted that the average annual base flow along Cienega Creek could be reduced by up to 0.09 cubic feet per second (cfs). For reference, Cienega Creek is located 10 miles due east of the center of the proposed Rosemont open pit.

In October 2013, in response to public comments received on the Preliminary Administrative Final Environmental Impact Statement (FEIS), SWCA conducted a review of the available stream flow data in Cienega Creek and Empire Gulch. Based on this review, SWCA developed a general approach (or analysis) to predict potential impacts to stream flow in Empire Gulch, Gardner Canyon, and Upper Cienega Creek due to groundwater drawdown. SWCA's analysis used a number of assumptions to translate the loss in stream flow, as estimated by the Tetra Tech model (in cfs), to drawdown in stream level (in feet of drawdown). A key assumption of the SWCA analysis was that a linear 1:1 relationship exists between drawdown in the regional aquifer and drawdown in the stream level. That is, a 0.10 foot drop in groundwater level in the regional aquifer will result in a 0.10 foot drop in stream level in Upper Cienega Creek. This memorandum provides an analysis of existing data that empirically contradicts the assumption of a 1:1 ratio of groundwater drawdown to a drop in stream level.

2.0 DATA USED FOR GROUNDWATER CROSS-SECTION

A search on the Arizona Department of Water Resources (ADWR) Groundwater Site Inventory (GWSI) database for wells in the near vicinity of Upper Cienega Creek produced water level data from three Index wells. Index wells are part of a statewide network of wells where, since about 1987, ADWR has collected groundwater level measurements on a routine basis. One of these three Index wells ((D18-17) 33ADA) was included in SWCA's December 26, 2012 *Documentation of Background Groundwater Fluctuations along Cienega Creek and Empire Gulch* Memorandum.

Index well (D-18-17) 32DBA is located approximately 2.3 miles west of the Cienega Creek stream channel. Index well (D-18-17) 33ADA, the one used in the SWCA document mention above, is located approximately 1.2 miles west of the Cienega Creek stream channel. Index well (D-18-17) 36CBC is located approximately 1.0 mile east of the Cienega Creek stream channel.

Table 1 below provides a summary of the construction data for the three Index wells. Locations of the wells are shown on Figure 1.

TABLE 1. WELL INFORMATION

Well ID	Registration No.	Depth of Well (feet)	Total Number of Water Levels	Number of "Pumping" Water Levels	Date Range of Water Level Measurements	Range of Depth to Groundwater Measurements (feet bgs)
D-18-17 32DBA	634321	226	22	3	1972 - 2014	90.80 – 118.60*
D-18-17 33ADA	616221	127	11	1	1982 - 2014	92.50 – 104.80*
D-18-17 36CBC	634356	180	30	2	1972 - 2014	126.10 – 144.20*

* indicates a "pumping" water level

As shown in Table 1, Index well (D-18-17) 36CBC had 30 groundwater level measurements from 1972 to 2014, (D-18-17) 32DBA had 22 groundwater level measurements from 1972 to 2014, and (D-18-17) 33ADA had 11 groundwater level measurements from 1982 to 2014.

The ADWR water level data show that water levels (pumping water levels excluded) have fluctuated through time in all three wells, from a range of 5.70 feet in well 36CBC to 25.30 feet in well 32DBA. The data also indicate there is a general declining trend of groundwater levels in all three wells.

A cross-section was developed using the groundwater levels and construction data (see Figure 1). Land elevations were obtained from U.S.G.S. topographic maps and Google Earth. Water levels measured on January 10, 2013 were selected as a basis of the cross-section since this date was recent and was common to all three wells.

Although a review of the January 10, 2013 water level data indicated some minor discrepancies, the overall range of the water levels was deemed acceptable. Even though the water level measured at well (D-18-17) 36CBC on January 10, 2013 was noted as a “pumping” water level, the measurement was 0.10 feet higher than the previous year’s measurement, which was not a pumping level. Water levels in well (D-18-17) 36CBC ranged from 4,305.80 feet above mean sea level (amsl) on January 8, 2008 to 4,304.10 feet amsl on January 14, 2014. Hence, although indicated as a pumping water level, the January 10, 2013 water level is within the non-pumping water levels of the previous five years and subsequent year.

The cross-section shown on Figure 1 illustrates that groundwater flow in the Upper Cienega Creek valley flows from the mountain fronts toward the creek (valley axis) then flows northward, generally parallel to surface flow. Water level elevations in the three wells define the hydraulic gradient across the stream valley. (The hydraulic gradient between any two points is the slope of the hydraulic head between those points.)

The hydraulic gradient as shown on Figure 1 was obtained by calculating the difference in head between each of the wells and the stream channel. The difference in head between wells (D-18-17) 32DBA and (D-18-17) 33ADA is 63 feet (4405 – 4342). Since the distance between the wells is 6,213 feet, the hydraulic gradient between these two wells is therefore 63/6213 = 0.010 (1%).

Similarly, the gradient between well (D-18-17) 33ADA and the stream channel is 0.02, or 2% (134/6362). The gradient between well (D-18-17) 36CBC and the stream channel is 0.001, or 0.1% (6/5469), indicating a much flatter gradient, and probably much more permeable aquifer on the east side of the stream. Even with a gradient of 0.001, groundwater on the east side of the stream (between Cienega Creek and the Whetstone Mountains) is still flowing toward the stream and contributing to the stream flow.

2.1 Assumptions

The assumption used in creating the cross-section shown on Figure 1 is that base flow in Cienega Creek is hydraulically connected to the regional groundwater flow system and that all three wells are completed in the same unconfined, homogeneous regional groundwater flow system. This assumption was used in the Montgomery & Associates (2010) and Tetra Tech (2010) groundwater models, and was also used in the SWCA analysis to develop the 1:1 relationship.

3.0 RESULTS

Surface and groundwater level elevation data were obtained and used in this exercise to create a cross-section (Figure 1) for the purpose of demonstrating in simplistic, but real, terms that groundwater, under unconfined conditions, flows from higher elevation to lower elevation (downhill), albeit slowly. In this specific case, the “downhill” point is Cienega Creek (valley axis). The groundwater level elevations from the two wells on the west side of Cienega Creek define a hydraulic gradient (or slope) between 1 and 2%. (Groundwater level elevations in wells 32DBA and 33ADA are significantly higher than the stream level, by 106 feet and 43 feet, respectively.) A much flatter gradient of 0.1% exists between the stream channel and the well on the east side of Cienega Creek. However, even at a gradient of 0.1%, groundwater flows toward the creek and contributes to stream flow.

The Tetra Tech (2010) groundwater model states that “after 150 years, the drawdown had not yet reached Cienega Creek”. After 1,000 years, the model predicted a total decrease in average annual base flow along Cienega Creek of 0.09 cfs, which was “less than three (3) percent of the simulated base flow.” Using SWCA’s simplistic 1:1 relationship between groundwater drawdown and surface water flow, a three (3) percent decrease in water levels in the wells used for this discussion would result in a water level decrease of between 3 to 4 feet. Although Index well (D-18-17) 33ADA, which is located approximately 1.2 miles west of the stream channel, has seen a total decrease of 5.70 feet in groundwater elevation from March 1982 to January 2014, Cienega Creek still has flow.

If, under worst-case scenario groundwater drawdown from the Project decreased groundwater levels in the two wells located on the west side of Cienega Creek, the hydraulic gradient between the wells and the creek would also decrease. Using the 0.1% slope (from the east side of the creek) as the worst-case scenario, a decrease in gradient to 0.1% on the west side reveals that wells 32DBA and 33ADA could experience a water level decrease of up to 93 feet and 36 feet, respectively, and still contribute stream flow to Cienega Creek.

This simplistic exercise does not consider factors such as recharge sources, hydraulic conductivity of the aquifer or fluvial system, stream length/width, intervening faults/barriers, and other pertinent factors. The purpose of this analysis was to demonstrate that applying a 1:1 relationship between groundwater level drawdown and stream flow drawdown is not valid or appropriate. As demonstrated, wells 32DBA and 33ADA could experience several tens of feet of drawdown and the aquifer would continues to contribute to stream flow in Upper Cienega Creek.

4.0 REFERENCES

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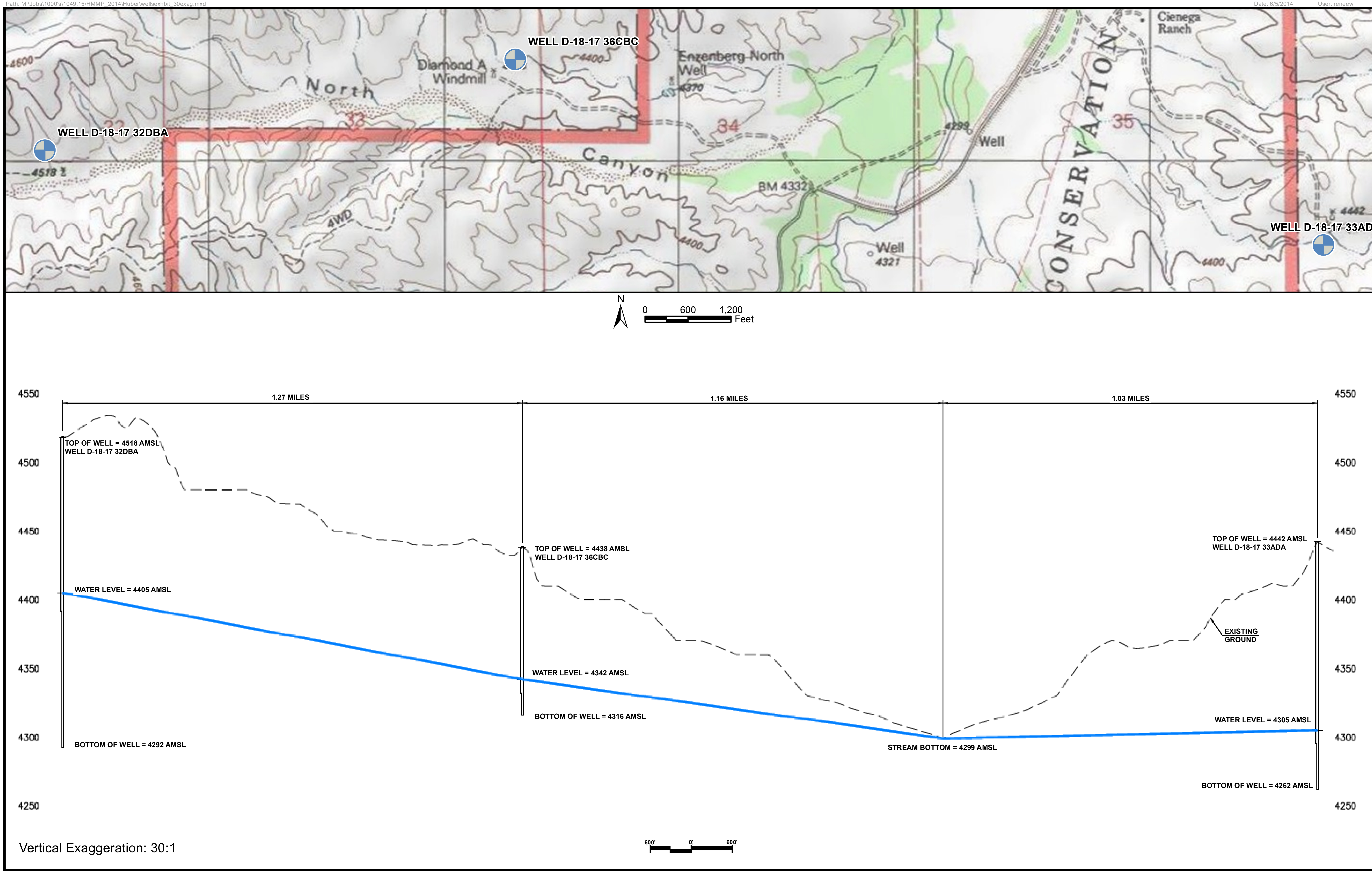
FIGURES


WELL D-18-17 36CBC
WELL D-18-17 32DBA
WELL D-18-17 33ADA
Diamond A Windmill
Enzenberg North Well
North Canyon
Cienega Ranch
CONSERVATION
BM 4332
Well
Well 4321
4WD
33
34
35
N
0 600 1,200 Feet
1.27 MILES
1.16 MILES
1.03 MILES
TOP OF WELL = 4518 AMSL
WELL D-18-17 32DBA
WATER LEVEL = 4405 AMSL
BOTTOM OF WELL = 4292 AMSL
TOP OF WELL = 4438 AMSL
WELL D-18-17 36CBC
WATER LEVEL = 4342 AMSL
BOTTOM OF WELL = 4316 AMSL
STREAM BOTTOM = 4299 AMSL
TOP OF WELL = 4442 AMSL
WELL D-18-17 33ADA
WATER LEVEL = 4305 AMSL
BOTTOM OF WELL = 4262 AMSL
EXISTING GROUND
4550
4500
4450
4400
4350
4300
4250
Vertical Exaggeration: 30:1
600' 0' 600'